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WHO.

EUROPEAN COOPERATION ON ENVIRONMENTAL HEALTH ASPECTS OF
THE CONTROL OF CHEMICALS. SAFE PROCESSING AND ULTIMATE
DISPOSAL OF REDUNDANT PRODUCTS CONTAINING OR EMITTING
POTENTIALLY TOXIC CHEMICALS 1983.

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ESCI

European Cooperation on Environmental Health
Aspects of the Control of Chemicals

Safe Processing and Ultimate Disposal
of Redundant Products Containing or Emitting
Potentially Toxic Chemicals

Draft Guidelines



World Health Organization
Regional Office for Europe
Copenhagen

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I. Introduction

1.0 Scope

Hazardous and toxic materials are present in almost all sectors of society today. The increasing use of toxic chemicals for processing and incorporation into finished products creates a potential health problem of very considerable proportions.

Hazardous and toxic wastes are generated by many sectors of society including the manufacturing industries who produce the chemicals, through those industries that use or incorporate the substances in their products to the consumers who must dispose of such products when they have served their useful life.

Industry uses potentially toxic organic chemicals for the production of solvents, plastics, drugs, detergents and a multitude of organic based materials. Some inorganic toxic substances are generated by plating, ore extraction and many other metal industries. The agricultural sector uses potentially toxic chemicals extensively for pest and weed control.

The scope of this document will attempt to encompass all types of potentially toxic and hazardous materials and describe the range of methods which might be used for their safe and satisfactory ultimate disposal. Such disposal may be rendered necessary because these chemicals or products have served their useful life. Alternatively newly identified hazards or perceived risks may have rendered them no longer acceptable. As a result the use of these chemicals may be banned by regulatory agencies.

To illustrate the magnitude of the potential problem, Table 1 shows the projected 1982 production in the U.S.A. of some of the major organic chemicals.

Table 1. Chemical Production in the U.S.A., 1982 projections

<u>Chemical</u>	<u>Projected Production</u> <u>lbs</u>	
acetic acid		1.3 x 10 ⁶
acetone	1.0 x 10 ⁶	
acrylonitrile	0.9 x 10 ⁶	
benzene	0.7 x 10 ⁶	
butadiene	1.5 x 10 ⁶	
cumene	1.7 x 10 ⁶	
cyclohexane	0.9 x 10 ⁶	
ethylene	13.9 x 10 ⁶	
ethylene glycol	1.9 x 10 ⁶	
formaldehyde	2.7 x 10 ⁶	
methanol	3.9 x 10 ⁶	
phenol	1.3 x 10 ⁶	
phthalic anhydride	0.5 x 10 ⁶	
propylene	6.8 x 10 ⁶	
styrene	3.2 x 10 ⁶	
toluene	0.5 x 10 ⁶	
xylene	2.0 x 10 ⁶	

(Source: Chemical and Engineering News, Dec. 21, 1981).

When the production figures for organic chemicals in Japan, Western Europe, Canada, the Middle East and Eastern Europe are added, it is clear that the dependence on products derived directly or indirectly from organic chemicals may be expected to continue in the years to come.

Recent years have seen a great deal of research development activity, as well as operating experience, in methods of handling, treating and disposing of hazardous materials.

Because of this, more is now known about the capabilities of established methods of dealing with hazardous waste and about the environmental behaviour of various chemicals. There have also been developments of new, or variations of existing processes.

There is a need to offer guidance on the suitability of various processes now available for the ultimate disposal of toxic and hazardous chemicals that have outlived their usefulness or have been banned by governments due to their extremely hazardous nature.

Before an assessment can be made of the most suitable technology in any particular case, it is necessary to consider the nature of the material as well as the concentrations of specific hazardous chemicals. In many cases the material may be very complex. It may range from a fairly pure (and therefore concentrated) chemical condemned by regulation, through waste to a range of chemicals released in a

factory or transportation accident and therefore mixed with soil, air or water. It may further be a highly complex uncharacterized mixture from previous improper disposal activities, or even soil contaminated with low concentrations of known chemicals.

Although desirable, it is not essential, and in practical terms almost impossible, to have a complete specification of the material. Classification systems describing types rather than specific chemicals are therefore very helpful. In many cases it is possible to apply knowledge of a particular technology to deal with particular classes of chemical or material.

Classification systems themselves, however, can be complicated and mutually inconsistent. It may therefore be helpful in this assessment to discuss the systems currently in use, before going on to assess disposal technologies. Section II of this guideline document deals with this matter.

2.0 Objectives

The objectives of this document are to:

a) identify industrial sources and the classes of hazardous chemicals and wastes which they produce.

b) identify a broad variety of technologies which may be applicable to disposing of redundant hazardous and toxic chemicals.

c) provide guidance on relatively well-established processes which are known to be suitable for dealing with some classes of hazardous materials.

d) assess innovative processes which may have future applications.

3.0 Risk analysis

In the process of selecting a process (and site) for the ultimate destruction and/or disposal of a toxic or hazardous material, some form of analysis of risk should be undertaken. This fairly new science is still somewhat imperfect but certain aspects of it are slowly gaining acceptance. It is, of course, not possible in this short document to cover all aspects of this new science and the reader is referred to the many authoritative works on the subject. Here we will simply introduce the idea and its relevance to the safe processing and ultimate disposal of toxic substances.

The concept of risk originally was related to the occurrence of death and therefore could be easily quantified as a simple probability. As society's use of chemicals grow, it has become clear that the consequences of exposure to some toxic substance could be considered as "worse than death".

Thus the concept of risk has now had to consider both the probability of an event taking place and the consequences of the event.

Risk analysis now includes both the consideration of the risk itself (i.e. the possible exposure to an event which may cause loss or injury) and the hazard (i.e. the consequences of the event actually occurring).

A risk analysis therefore addresses three questions:

1. What may happen?
2. What is the probability of it happening?
3. What are the consequences of it happening?

In terms of disposal of toxic materials, the process consists of four steps which are discussed in the following sections.

3.1 Risk identification

The identification process may be undertaken by clinical observations of some toxic responses for a small number of cases for particular substances which require handling and disposal.

Alternatively, it may be determined descriptively by examining cases of intoxication in retrospect using studies of control populations to validate the findings. Finally the data may be projected into the future by using cohort* study methods.

Unfortunately, all of these methods require some kind of human exposure and therefore are not considered appropriate for experimentation and observation. However, where such past data are available, as in the case of a previous chemical accident, it should be carefully evaluated and used where possible because it does provide a real and less challengeable data base from which to make decisions.

A further, more common, method of evaluating the human health risk consists of toxicological studies. Such studies usually using laboratory animals are of short duration and limited direct applicability. However, to offset these shortcomings this methodology does have the potential for determining sub-acute toxicity, reproductive (teratogenic), mutagenic, metabolic and chronic effects as well as the more obvious acute effects. Costs of some tests, however, are high and the metabolic interpretation is complex in the case of the less expensive tests (AMES Test).

Short term toxicity tests are now becoming popular to detect specific events which are precursors to other physiological effects such as cancer.

Some new bioanalytical methods are under development (Safe, 1981) which measure the toxic activity rather than the concentration of individual components.

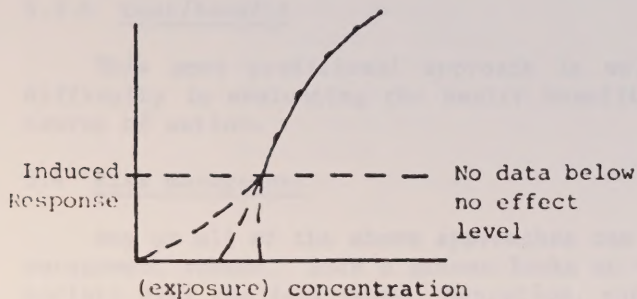
* Cohort: A group of persons with some characteristics in common e.g. live in same area, same age, sex, state of health, socio economic status, race or religion.

3.2 Risk estimation

Many agencies have adopted as a "safe" level, 1/100 of that dose which causes observable effects in laboratory animals. The question of estimating a risk for an entire population becomes more difficult. One possible threshold may be described as the level which has no effect on the most sensitive member of the population -

i.e. Population threshold = min. individual threshold

The observed no effect level (NEL) very much depends upon the sample size and so will vary with populations. The slope of the dose response curve is also of considerable significance.



Since by definition there is no data on induced response available below the "NEL", it is not possible to predict the shape of the curve below the no effect level. See Figure 1.

Figure 1. Dose-Response Toxicity Curve

3.3 Risk evaluation

This process is severely limited by the methodology available at present. It is normal to consider benefits also when considering the risks because the risk/benefit ratio can give assistance in comparing risks in the decision-making process (e.g. the risk of disposal of a substance at a place using a specific methodology versus the benefit of having removed the substance from the environment).

There are several frameworks within which risk evaluation can occur.

3.3.1 Zero risk principle

This approach attempts to achieve a zero risk situation. This, of course, is conceptually impossible to achieve. What this approach does, however, is attempt to minimize the risk to the lowest possible value. A variant would be zero measurable risk, where the object is to place the risk under the lowest available measurable boundary.

3.3.2 Comparative/alternative risks

Using this procedure the risk of the handling and disposal proposal under study is compared with other risks which society find acceptable. The option may also be compared with alternative courses

of action to produce the same results (e.g. set up portable incinerator to burn the substance where it is located rather than move it to a central location). The difficulty here is that the population required to take the risk may not be the same as the one which will enjoy the benefit.

3.3.3 Risk/benefit

Health benefits are usually very difficult to evaluate in explicit terms. As a result, this procedure involves a rather vague definition of the benefits. The total destruction of the stock of a substance which is known to have detrimental health effects (and has been banned) clearly has some human health benefits even though they may be difficult to quantify.

3.3.4 Cost/benefit

This more traditional approach is well known, but it also has difficulty in evaluating the health benefits accruing to a particular course of action.

3.4 Risk management

Any or all of the above approaches can be part of a complete risk management scheme. Such a scheme looks at the management of risk in a society over the long term. Education, consumer information programmes, and product labelling assist in the perception of risk. Environmental control through legislation and the regulation of safe procedures contribute to the regularization of risk.

Regulation may be described as a set of societal rules of behaviour supported and articulated by statute. Failure to observe such rules may result in the application of penalties. This procedure, however, has significant administrative costs to Government which must be considered carefully before applying this strategy, particularly as there is an expressed trend in many countries today towards deregulation.

II. Classification of chemicals and materials

1.0 Criteria

There are various properties which may make a chemical or a material hazardous. Depending upon the level of detail required, a number of different properties could be considered:

Table 2. Hazardous Properties of Chemicals

Reactivity Properties

Flammability
Explosivity
Corrosivity
Radioactivity
Oxidizing/Reducing

Toxicity Properties

Acute toxicity
Sub-acute toxicity
Chronic toxicity
Sub-chronic toxicity
Carcinogenicity
Mutagenicity
Teratogenicity
Metabolism
Allergic Response
Infectivity

For the purposes of this guideline document, the following properties may be considered most important:

oxidizing/reducing
flammability
explosivity
corrosivity
carcinogenicity
toxicity

Organic wastes may also be conveniently classified as either non-persistent or persistent. The major differences in the impact of these two classes of organic compounds is shown in Tables 3 and 4.

Table 3. Non-Persistent Organic Wastes

<u>Examples</u>	<u>Hazards</u>
Oil, low molecular weight solvents, some biodegradable pesticides (organo-phosphates, carbamates, triazines, anilines, ureas), waste oils, most detergents	Primarily point source, short term problems Primarily to environment and biota at the point source Toxic effects occur rapidly after exposure (acute and subacute)

The problems of non-persistent and persistent pollutants may be comparable; but due to the higher reactivity of the former group they may create greater risks at the point source of release. The persistence of a substance also depends upon the environmental conditions prevailing (e.g. oil is very persistent under ice).

Table 4. Persistent Organic Wastes

<u>Examples</u>	<u>Hazards</u>
High molecular weight hydrocarbons chlorinated hydrocarbons and aromatic hydrocarbons, some pesticides (chlorinated insecticides, hexachlorobenzene, DDT, DDE, lindane); PCBs, phthalates	Point source and remote locations, potential long term problems Transport of organic waste from the source can result in widespread contamination and bio-concentration in the food chain Immediate toxic effects (acute and subacute) may occur at the point source. Environmental transport may expose biota to lower levels of the pollutant resulting in chronic toxicity

Halogenated hydrocarbons and aryl hydrocarbons are widely used in both developed and developing nations. The industrial and commercial utility of several of them may be directly related to their many common chemical properties including:

- 1) high chemical stability (resistance to oxidation, reduction and hydrolysis),
- 2) resistance to photochemical degradation,
- 3) inflammability
- 4) high lipophilicity and miscibility with a large number of organic solvents,
- 5) resistance to biological breakdown processes.

Polychlorinated biphenyls (PCBs) typify a halogenated hydrocarbon formulation which exhibit these characteristics. PCBs were used in the past and in many cases are still in use (in closed applications) as flame retardants, organic diluents, dielectric fluids in capacitors and transformers, heat exchange fluids, plasticizers and immersion oils. Other chemicals in this group include the chlorinated naphthalenes (PCNs), terphenyls (PCTs), hexachlorobenzene (HCB) and the polybrominated biphenyls (PBBs), as well as the polychlorinated dibenzofurans (PCDFs), dibenzo-p-dioxins (PCDDs) azobenzenes and azoxybenzenes (PABs). These latter compounds are formed as by-products in the preparation of chlorinated phenol-derived chemicals (PCDDs and PCDFs), PCNs and PCBs (PCDFs), chlorinated anilines and their derived pesticides/herbicides (PABs). They may also result from the combustion of organic waste containing a source of chlorine (PCDDs, PCDFs, HCB and PCBs).

Many other halogenated hydrocarbons have widespread applications as pest control agents. 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane (DDT), is an example of a halogenated aromatic hydrocarbon which has been primarily used as an insecticide for the control of insects. Many other pesticides including the hexachlorocyclohexanes (eg. lindane), the hexachlorocyclopentadiene-derived hydrocarbons, and hexachlorobenzene were developed for the control of a diverse group of pests. Even though these compounds have been very effective, the use in many jurisdictions has been restricted, terminated or is under study. The initial findings concerning DDT have now been extended throughout the whole class of halogenated hydrocarbons and aryl hydrocarbons. Even though there has been no direct dose-response link established for many of these halogenated hydrocarbons, residues have been observed throughout the food chain including fish, wildlife and humans. The effects of this contamination are not fully understood and very little information is available on synergistic effects with other pollutants.

Considerable difficulty also exists in the appropriate disposal of many inorganics such as concentrated arsenical, mercurial, and beryllium wastes. Other inorganics such as finely divided metals, alkali metals and their alloys are also causing serious problems because legislation is making it more and more difficult to find legal and satisfactory disposal outlets for them.

The very chemical properties which made these chemicals effective are the same ones which now create the public concern. Table 5 summarizes some of these properties.

Table 5. Chemical and environmental properties
of halogenated hydrocarbons

<u>Chemical Property</u>	<u>Environmental Property</u>
Chemical stability	Environmental stability persistence and transport
Lipophilicity	Uptake into living species and storage of fatty tissues
Poorly biodegradable	Bioconcentration and biomagnification in species at higher trophic levels of the food chain

The question of whether a chemical or a material is hazardous in one or more of these respects can be a difficult one. There is no international agreement on detailed criteria, nor on methods of testing. For some aspects, for instance toxicity, specific dose-response data on many chemicals is scarce and it would be difficult or impossible to generate data on human toxicity.

This lack of agreement, however, need not be a serious problem. In some cases where a dispute arises, there may be a need for quantitative testing of specific materials. In general terms there is considerable agreement as to which chemicals and materials are potentially hazardous to humans or are potential threats to the environment. Furthermore, this document is concerned with deliberate disposal of redundant chemicals, accidents or cases of improper disposal, where the existence of hazard is not in doubt. It is not primarily concerned with matters of routine solid waste disposal activities.

It would be possible, although neither practical nor useful, to list all known chemicals and to suggest the best disposal technology for each in its pure form. It is neither practical nor possible to

list all the potentially hazardous materials and mixtures of chemicals that could arise. It is, however, practicable to use classification systems which will encompass the majority of materials.

Many different classification systems have been used by various authorities around the world. Conceptually, they are mostly of two main types: those based on the types of chemical contained in the materials; and those based upon the industries or industrial processes which generate and use them. Neither type is sufficient on its own. In some cases, nearly all chemicals and materials arising from a particular process will be hazardous; in others only a few may be hazardous.

On the other hand, the degree of hazard posed by a particular chemical or class of chemical may depend very much upon its concentration, physical form and other materials present; or in other words, upon the process from which it came.

In the following sections, guideline classification systems of both types will be given, followed by an example of a health/toxic response system and a compromise system which combines some of the best properties of all.

2.0 Chemical constituents systems

The system given below is based, with some modifications, on a listing used by the U.K. Department of Environment for 'special wastes' (DOE, 1981).

Organic

biocides and phytopharmaceuticals

heterocyclic organic compounds (containing oxygen, nitrogen or sulphur)

hydrocarbons and their oxygen, nitrogen and sulphur compounds

organic halogen compounds (other than inert polymers)

pharmaceutical and veterinary compounds

tarry materials and distillation residues

Inorganic

acids

alkalis

asbestos materials

inorganic cyanides

inorganic halogen compounds

inorganic sulphur compounds

laboratory chemicals

peroxides, chlorates, perchlorates, azides

phosphorus and its compounds

toxic metals and their compounds:

antimony
arsenic
barium
beryllium
boron
cadmium
copper
chromium
lead
magnesium
mercury
nickel
selenium
silver
tellurium
thallium
vanadium
zinc

In addition to systems such as this, there are various comprehensive listings of specific hazardous chemicals, sometimes giving limited toxicity or other information about each. Sources of some such listings are given in Appendix B.

3.0 Industrial based systems

Table 6 lists firstly the primary industrial activities which produce (producers) and handle hazardous chemicals or materials, and secondly the applied industrial activities (users) which handle and utilize those materials. These industries may, in the course of their activities, alter the properties of the various feedstocks sufficiently to produce hazardous wastes from materials that were not initially hazardous or toxic. Examples may be metal finishing processes in which waste materials may contain mixtures of several toxic metals, cyanides, solvents and complexing agents.

Table 6. Primary producers and industrial handlers and users
of toxic materials

PRIMARY ACTIVITIES

Mineral extraction

Petroleum	production refining petrochemicals
Chemicals	organics inorganics intermediates alkalis and chlorine paints, soaps, cleaners pesticides agricultural pharmaceuticals explosives plastics and rubber
Metals	foundries (ferrous) foundries (non-ferrous) metal finishing
Food	
Textiles	
Pulp and paper	

APPLIED ACTIVITIES

asbestos products
automotive industry
armaments
aerospace industry
electrical
electronic
graphic arts
heavy engineering
industrial cleaning
leather tanning
metal finishing
roofing
wood products

4.0 Health/toxic response systems

The difficulties in classifying chemicals in terms of their danger to human health (or their toxicity) are well known. They can be seen as multidimensional problems. One dimension is recognizing the difference between the toxicity of almost every substance - given high enough doses - and the more informative dose-response rates that one derives from, for example, experiments on laboratory animals. Drawing

the boundaries where "toxic" is a meaningful concept is related here to size of dosage. A further dimension is the interference of one substance on another at very low doses. The time dimension of the problem is the problem of relating acute toxicity to chronic toxicity. Chronic toxicity is much more difficult to use as a classification system, since there is so little available research. Methods of translating from acute to chronic toxicity potentials will become more acceptable as the data base improves.

Even if one were able to sketch out the above indicators and thereby point to possible classification systems, a number of other concerns emerge. One is bioavailability (and bioaccumulation), which assesses such characteristics of the chemical as persistence. Even assuming that dose-response information is available, the question remains what kind of a dose is one likely to get in the real world? A second is the possible synergistic effects of two or more chemicals acting together in a situation with potential populations at risk.

The complexity of these characteristics and their obvious inadequacy when used singly in the formulation of classification systems has notably resulted in the U.S. EPA using all of the above characteristics (and others) in the Resource Conservation and Recovery Act regulations (1980). Such an approach may create confusion due to the very large body of information and the high likelihood of internal inconsistencies.

4.1 Acute toxicity testing

The original concept of risk was related to the most obvious consequences of exposure to chemicals, namely death or serious injury. It is possible to assign these risks as at least some rough probabilities. In this sense, accidents and industrial exposures in the past have provided us with retrospective case histories for a number of chemicals. Toxicological studies have been introduced to complement the historical data, usually using laboratory animals, and with the intention of establishing the median lethal dose (LD₅₀). This is the quantity of a material that can be expected to kill 50% of the test animals under a prescribed set of conditions and with a given probability. This widespread test, although not perfect by any means, can give both broad parameters of possible activity and some indication of target organs (and organisms) and their susceptibility. And since the acute doses have been determined for many chemicals, a rough and ready classification system could be developed as outlined in Table 7. The mode of entry (contact) of course is important. Substances which might be lethal if ingested may be harmless if only skin contact occurs.

It should be stressed that this classification system would be artificial, or have only a limited relationship to effects in practice. Not only are people subjected to multiple stresses in the non-laboratory conditions of daily life, they also have different suscep-

tibilities depending upon age, weight, size, and other characteristics. Furthermore, sub-acute doses may not kill, but may cause neurological or behavioural changes (e.g. dioxin) at very low doses.

Table 7. LD₅₀ Values as Criteria for Classifying Chemicals^a

Class	Toxicity Rating	LD ₅₀ dose ^b (oral)
6	Super Toxic	>5 mg/kg-bw
5	Extremely Toxic	5-50 mg/kg-bw
4	Very Toxic	50-500 mg/kg-bw
3	Moderately Toxic	0.5-5 g/kg-bw
2	Slightly Toxic	5-15 g/kg-bw
1	Practically Non-Toxic	>15 g/kg-bw

^adeveloped after Casarett and Doull (1975)

^bprobable human acute lethal dose

4.2 Chronic toxicity testing

Chronic toxicity testing is controversial because of the difficulties in extrapolating from acute toxicity testing, and because of the difficulty in establishing cause-effect relationships over extended periods. Chronic toxicity testing ranges over the following possible effects:

- a) carcinogenesis
- b) mutagenesis
- c) teratogenesis
- d) peripheral neuropathogenesis
- e) reproductive pathology
- f) psychotoxicity
- g) cardiovascular pathology
- h) embryo toxicity, and
- i) immunosuppression.

Development of a classification system based on these tests is still at a primitive stage. Hayes (1972) proposed that a Chronicity Factor could be given to a chemical, based on the ratio of single acute LD₅₀ dose to a dose given daily over 90 days that also results in 50% mortality at the end of that time. A ranking scheme is suggested here involving a chemical's chronic toxicity hazard rating (called C_{tox}) which would be made up of a "Chronicity Index" (CI) and a "Potency Factor" (PF), so that:

$$C_{tox} = CI + PF$$

The "Chronicity Index" (CI) is a ratio between the single acute LD₅₀ dose, and a dietary dose (ED) that would produce a statistically significant chronic effect in some percentage (x%) of a test population:

$$CI = LD_{50}/ED_x$$

The "Potency Factor" (PF) relates the orders of magnitude this effect (ED_x) is greater than some chronic reference dose of 1 mg/kg-bw/day. For example, if a chronic dose (ED_x) showed a statistically significant effect at 0.00001 mg/kg-bw/day (1x10⁻⁵), this is 10⁵ less than the reference dose of 1 mg/kg-bw/day and the PF is therefore -5. The chronicity index (LD₅₀/ED_x) is useful for identifying those chemicals that are chronically toxic (eg. carcinogenic) at doses much lower than those exhibiting acute toxicity.

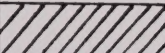
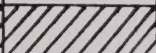
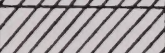
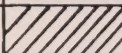
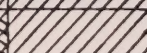
Examining the chronic toxicity (C_{tox}) rating chart we may see that Aroclor 1260 (PCB) which would only be considered as being "slightly toxic" (see Table 7) based solely on its LD₅₀ dose of 10,000 mg/kg-bw, has a chronic toxicity (C_{tox}) rating as "high hazard" because it is suspected to be carcinogenic at a significantly lower dose (100 mg/kg-bw/day) giving a CI value of 100 and PF of +2.

Using this technique we find that TCDD (dioxin) would be "super toxic" (see Table 7) based on its LD₅₀ (0.1 mg/kg-bw/day). However, under certain laboratory conditions and on certain animals, it is carcinogenic at a dose of 0.0001 mg/kg-bw/day, giving a PF (at 4 orders of magnitude lower than the reference dose of 1.0 mg/kg-bw/day) of -4. The resulting C_{tox} gives TCDD a rating of Supreme Toxic indicating that it is one of the most potentially toxic chemicals known to man.

A future classification possibility depends on new bioanalytical methods under development (Safe, 1982). These measure the toxic activity, rather than the concentration of individual components of chemicals. For example, there are 209 possible congeners of PCB's and only 182 have been synthesized from which comparative standards can be used for identification. For individual analysis, separation must first of all be undertaken, a very elaborate procedure. Structural activity studies have indicated that within the class of halogenated aromatics there is a correlation between those congeners which are toxic and those which induce a measureable enzyme (microsomal cytochrome P-448) dependence. This permits quantification of toxicity in mixed substances containing a variety of halogenated aromatic congeners, each of which has a different toxicity. Ultimately, structural activity may be the most accurate classification system.

4.3 Bioavailability

Bioavailability is a measure of the factors that will influence the probable dose a particular receptor will receive. Some aspects of

Potency Factor (PF)	Chronicity Index (CI)					Hazard
	>10	10-50	50-100	100-500	>500	
-5						Supreme
-4						Supreme
-3						Extreme
-2						Extreme
-1						Severe
0*						Severe
+1						High
+2						High
+3						Moderate
+4						Moderate
+5						Low
	Low	Slight	Moderate	High	Severe	Hazard Rating

* PF = 0 is the reference dose of 1 mg/kg-bw/day to which all other doses (ED_x's) are compared.

Shaded areas of chart represent "Ultimate Hazard" (ie. top priority chemicals) and "Lowest Hazard" chemicals. Cross hatch representing the highest and lowest hazards respectively.

Figure 2. Chronic Toxicity Rating Chart.

bioavailability, such as persistence of chemicals in various media, can be ascertained through testing to determine the form and rate of degradation in the affected environment. It is obvious that some of these tests (e.g. mobility) are frequently chemical-physical, and could therefore be related to the classification systems previously mentioned.

Persistence in the environment of a chemical may permit bioaccumulation to a level where toxic symptoms finally appear. Biomagnification up the food chain can turn insignificant trace levels of chemicals into serious threats to health. Once again, the basic knowledge of the intricate pathways of uptake concentration and conversion are not adequate to propose satisfactory classification systems. Information concerning chemical type (organic or inorganic) and form may provide some guidance to toxicity.

4.4 Synergistic effects

Testing in the laboratory is generally conducted using a pure chemical compound, while it is more likely that a combination of compounds will occur in the environment. An ideal classification system would begin with each chemical compound and then map out its interactions with every other possible combination of compounds. This is clearly an impossibility in practice.

The types of chemical interaction can be described:

1. Independent - the chemicals have different modes of action, and therefore produce different effects, as if the other chemicals were not present.
2. Additive - the chemicals together would have an effect based on the sum of the individual effects.
3. Synergistic - the chemicals would have a greater effect than the simple sum of the individual effects (also known as potentiation).
4. Antagonistic - the chemicals would have a less than additive effect on each other (also known as inhibition).

The most difficult of the above groups to predict or systematize is the synergistic interaction, since a completely harmless chemical when joined by another completely harmless chemical may result in an extremely dangerous mixture. Unless one could develop a ranking system whereby tendency to interact with other chemicals were measurable, the only basis for such ranking must be on an impact-by-impact analysis. Finney (1952, 1971) and adaptations by Smyth et al. (1969) provide suggestions for model approaches to acute joint toxicity.

5.0 Compromise systems

For materials which arise regularly as wastes in industrial activities, it has sometimes been found convenient to use a compromise classification scheme which incorporates chemical nature, physical form and possibly process source. Two examples of such schemes are given below. These schemes were developed to deal with wastes which regularly arise and for which disposal is carefully regulated. This document is mainly concerned with materials that must be destroyed or disposed of to avoid unsatisfactory release into the environment. It is also concerned with the satisfactory and safe disposal of toxic materials arising from accidents or poor disposal practices. The scope of this document includes any or all hazardous chemical materials, even those which may only exist as intermediates within a process, since they could be released in an industrial accident. However, compromise systems may still be found useful: in dealing with hazardous materials from an accident or from an abandoned dump, the officer responsible for selecting the proper disposal method will need to know the physical form and the constituents (if at all possible).

SYSTEM 1. (Source: Ayres, 1979)

Types of Wastes

- (1) Solid toxic
 - (a) Cyanides
 - (b) Metal bearing and other inorganic
 - (c) Asbestos
 - (d) Pharmaceutical and laboratory reagents
- (2) Acid solutions or sludges
 - (a) Metal bearing
 - (b) Without metals
- (3) Alkaline solutions or sludges
 - (a) Metal bearing
 - (b) Without metals
- (4) Neutral solutions
 - (a) Inorganic
 - (b) Organic
 - (c) Mixed-organic and inorganic
 - (d) Cyanide solutions
 - (e) Metal bearing
- (5) Oily wastes
 - (a) Mineral
 - (b) Fatty (i.e. animal/vegetable)
 - (c) Oil-water emulsions
- (6) Tarry wastes

- (7) Solvent wastes
 - (a) Non-chlorinated
 - (b) Chlorinated
- (8) Organic materials
- (9) General factory waste contaminated by various toxic materials

SYSTEM 2. (Source: Hertfordshire County Council, U.K.)

(1) Principally Solid

- (a) Metal bearing (general)
- (b) mercury, cadmium
- (c) lead, arsenic, antimony
- (d) inorganic
- (e) organic
- (f) cyanides, sulphides, selenides, tellurides
- (g) asbestos bearing
- (h) pharmaceuticals/cosmetics
- (i) mixed laboratory chemicals

(2) Aqueous Acidic: solutions or sludges (pH <4)

- (a) metal bearing
- (b) inorganic
- (c) organic

(3) Aqueous Alkaline: solutions or sludges (pH >10)

- (a) metal bearing
- (b) inorganic
- (c) organic
- (d) cyanides, sulphides, selenides, tellurides

(4) Aqueous Neutral: solutions or sludges (4 < pH <10)

- (a) metal bearing
- (b) inorganic
- (c) organic
- (d) cyanides, sulphides, selenides, tellurides
- (e) oily (1% > mineral oil < 10%)

(5) Oils

- (a) mineral oils (<20% other liquids)
- (b) mineral oils (>20% other liquids)
- (c) oil/water (10% < water < 80%)
- (d) greases, fats, waxes, non-mineral oils

(6) Organics

- (a) polymeric material and pre-cursors
- (b) paint waste
- (c) ink/dye waste
- (d) tars/phenols (distillation residues/degradation products)

(7) Solvents (<20% solids)

- (a) non-halogenated (<10% halogenated)
- (b) halogenated/mixed (>10% halogenated)
- (c) mineral oil sludges (interceptor or tank-cleaning wastes)

(8) Solvent Sludges (>20% solids)

- (a) non-halogenated (<10% halogenated)
- (b) halogenated/mixed (>10% halogenated)
- (c) mineral oil sludges (interceptor or tank-cleaning wastes)

(9) Other Wastes

- (a) general factory wastes contaminated by various toxic metals; diatomaceous earth filter cakes, contaminated filters, etc.
- (b) empty contaminated containers
- (c) pressurized vessels: gas cylinders, aerosols
- (d) contaminated soil
- (e) biocides: solid
- (f) biocides: liquid

III. Available processes for treatment/disposal

1.0 Principles

Three fundamentally different approaches can be identified for the management of potentially hazardous materials. These are:

- a) Alter the material before it becomes a residual so that it is no longer hazardous;
- b) Dilute the material within the environment to a level at which the potentially toxic components are no longer hazardous;
- c) Permanently isolate the material from the environment.

The absolute permanence of techniques based on the principle of isolation may be challenged. In addition, the implied burden of perpetual monitoring may be unacceptable. However, if isolation lasts long enough to allow natural alteration combined with slow release (i.e. dilution), it will have played a vital part. Isolation may also provide adequate time for technology to advance and provide safe and satisfactory means for detoxification. In the case of some

toxicants of course (e.g. metals) isolation or recovery/reuse is the only option since they cannot be destroyed.

In practice the objective of ultimate disposal technologies must be to ensure that either the residuals themselves are rendered innocuous or that release into the environment occurs at such a rate that no hazard results and environmental impact does not exceed acceptable limits.

The treatment technologies identified in the following section can all be seen to be examples of one or more of the three approaches described above.

In the subsequent sections, process selection and evaluation will be judged on their ability to achieve the above objective for the various classes of hazardous materials. A major difficulty is to decide upon acceptable ambient concentrations (limits to release).

2.0 Classes of processes and variations

Processes and unit operations which might be used to detoxify or dispose of various hazardous materials are presented under four headings.

- thermal treatment to produce residuals;
- pre-treatment to produce residuals;
- land/sea disposal of materials directly or of residuals from thermal and pretreatment;
- reuse and recycling.

Thermal treatment processes are based on the concept of altering the material or its intrinsic properties to produce a residual which is considered less hazardous. Other pre-treatment processes may incorporate both the alteration and isolation principles. Land/sea disposal systems can incorporate any of these principles, though perhaps less controlled than in some other pretreatment systems. It is important to recognize that residuals will result from all forms of treatment. These residuals may take the form of solids, liquids or gases. Their control is of the utmost importance since they generally constitute as much as 10-50% of the original waste by volume.

In the following sections, various processes are listed. In some cases these are variations of fairly similar processes rather than radically different options.

2.1 Thermal processes

Incineration:

- open pit
- open hearth
- multiple chamber
- rotary kiln
- fluidized bed
- liquid combustor
- molten salt
- incineration at sea
- incineration in cement kiln

Calcination

Pyrolysis

Microwave plasma arc

Wet-air oxidation

2.2 Listing of pretreatment processes

2.2.1 Biological

- Activated sludge
- Percolating filter (trickling filter, bacteria bed)
- Rotary biological contactor
- Aerated lagoon
- Fluidized bed
- Composting
- Anaerobic digestion
- Anaerobic filter
- Stabilization pond

2.2.2 Physical/chemical

Phase separation -

- filtration
- centrifugation
- sedimentation/thickening
- evaporation
- emulsion cracking
- oil/water separation

Component separation -

- ultrafiltration
- reverse osmosis
- dialysis
- electrodialysis
- liquid/liquid extraction
- gas stripping/steam stripping
- foam fractionation
- ion exchange
- adsorption (activated
 - carbon, peat moss,
 - peanut hulls,
 - ground rubber,

sawdust,
corn husks,
alumina,
silica)

Alteration of chemical state -

precipitation (hydroxide, sulphide,
carbonate, chloride, other)
neutralization
hydrolysis
oxidation (chemical, electrolytic,
catalytic/photolytic, carbon
adsorption with reactivation)
reduction (chemical, electrolytic)

2.2.3 Solidification/encapsulation

Silicate-based processes - sodium silicate
- cement
- pozzolanic reactions
Organic polymer processes
Thermoplastic processes
Encapsulation
Vitrification

2.3 Land disposal

Non-secure landfill
Secure landfill
Co-disposal landfill
Land treatment
Deep well injection
Mineshaft disposal
Permanent storage in sealed containers

2.4 Sea disposal

Dilution in continental seas
Deep sea burial in sealed containers

IV. Process selection

Descriptions are not intended to provide detailed information on design and operational aspects of processes. Such information is widely available in many excellent reference works. Some of these are listed in the bibliography at the end of this document. They will be cited, where appropriate, in the text. In some cases the assessment procedure will also provide further details about the various technologies.

1.0 Criteria

An attempt will be made to assess each process according to the following criteria. In some cases, this framework will not be applicable or information is not available. This may be because some processes are very location-specific or proprietary, and full details are not made public for commercial reasons. Some risks may be considered as long term such as landfill.

(a) Waste form

Various types of materials
Various classes of chemical (and hazard)

(b) Safety and residuals

Inherent safety of process, residuals produced, level of control and monitoring needed.

(c) Impacts

Environmental impact of structures and operation
Health impact on a) process workers, b) adjacent community
Public perception of process

(d) Costs

Information where available on capital and operating costs.

Some general comments can be made which will apply to all of the processes.

With some techniques there may be many variations on the market and no attempt has been made to list them as separate processes here.

In practice it may be desirable to use several separate processes interlinked with each other. This would apply particularly to some of the phase separation/component separation processes. These might be used either before some other process (possibly to make more economical use of energy or chemicals) or after some other process (to reduce the volume of residuals going to ultimate disposal).

Technological methods used for hazardous materials management should be subjected to a high level of control. Due to the hazardous nature of the materials being handled, failure of technological devices can create serious problems.

Some potentially adverse features may be common to all technologies. Increased traffic of tankers, trucks and containers carrying hazardous materials is one of these. Increased noise and

occasional odours may be others. To some extent, these depend upon 'good housekeeping' and most facilities have the potential to be either good or bad neighbours, depending upon management standards and procedures.

The public may be antagonistic to an installation, particularly if it is to be located close to them. This antagonism may be less related to the intrinsic properties of the technology than to the image created by the marketing approach taken. Bad marketing can and frequently has resulted in good technological solutions being rejected by the public.

2.0 Thermal processes

2.1 Summary assessment

All thermal processes are designed to alter the nature of the material in some way, to produce residues which are less hazardous. Some of these processes are very similar. For instance, incineration, gasification and calcination processes relate mainly to the nature of the feed material, the reactor conditions and the treatment objectives, rather than to the physical type of plant used. The various types of plant used for one process might also be applicable to another.

Incineration is designed to provide for complete oxidation of organic components in the feedstock. The higher the organic content of the feedstock, the more suitable it is for incineration. This generally involves high temperatures (1000°C and higher) and a plentiful (controlled) air supply. If the organic content of the feed is not high enough, supplementary fuel will be needed to ensure complete combustion.

Pyrolysis is a similar process to incineration except that the air supply is restricted so that only partial oxidation of organic components occurs. The objective is to produce a usable high calorific value gas as one of the residuals, while at the same time changing the nature of the original components in the feedstock.

Calcination involves the same type of process as incineration and gasification but in this case applied to materials with a high inorganic content and some organic contaminants. It often requires supplementary fuel to support it. The process aims to produce a solid inorganic residue, free of organic contamination.

The range of plants named earlier in this document under the heading of incineration also encompasses those used for pyrolysis (fluidized bed) and for calcination (open hearth, multiple hearth, rotary kiln and fluidized bed).

The majority of licensed hazardous waste disposal facilities today (1983) use incineration (rotary kiln or liquid injection).

The following is an assessment of thermal processes in general, followed by assessments of individual processes where information is available.

- (a) Waste form. Solids, liquids, gases, tars, sludges, slurries and drummed materials can all be accommodated by some form of thermal treatment, with some types of plant accommodating more types of material than others. Commercial plants are often hybrids of several of the variations listed previously, or unique designs not listed here. One very versatile combination is the rotary kiln with afterburners. This combination can cope with a large variety of materials.

Thermal treatment can destroy virtually all organic chemicals if operated properly. In some cases toxic metals can be immobilized by incorporation in solid residues (e.g. calcination). The following list shows chemicals and materials which have successfully been treated by thermal techniques.

pesticides
PCB's
halogenated aliphatics
halogenated aromatics
solvents, strippers, thinners, hydrocarbons
isocyanates, nitrites, acrylonitriles, acetonitriles
organic acids, salts, anhydrides
hydrogen sulphide, mercaptans
phenols
vinyl chloride
pharmaceuticals
polymers, resins, still-bottoms
tars, acid tars
cutting oils, lube oils, animal oils, soluble oils
ethylene glycol, methylamines, methacrylates
styrene residues
separator sludges, digester sludges, detergent sludges
leaded sludges, oily sludges, tars and clays
polyester paint, PVC paint, latex paint
inks, dyes
explosives and munitions

More comprehensive listings of chemicals and materials suitable for incineration have been produced by Ottinger et al. (1973), noted in Powers (1976), and are reproduced in Appendix A.

For PCB's, pesticides and halogenated organics a temperature of 1000°C should be maintained for at least 2 seconds, with an adequate air supply, to assure complete destruction.

Pyrolysis involves complete conversion but incomplete destruction of organics. They may detoxify hazardous components in the feed, but afterburners would be needed if complete destruction is required (i.e. incineration). This combination may ultimately prove more cost- and energy-effective than simple incineration, but further research is required.

For materials with a low level of organics but high concentration of inorganic solids, calcination may prove to be the best alternative. This would be particularly true if heavy metal contamination were present, as the solid residue from calcination is reasonably resistant to leaching. However, the gaseous products can be hazardous and caution should be exercised in their release.

Direct incineration techniques are not well suited for explosives, propellants and munitions, because of the danger of accidents in enclosed systems, and the lack of control in open pit incinerators. Wet air oxidation (WAO) might be more suitable for such materials prepared as aqueous slurries. WAO is probably the most suitable thermal technique for systems consisting mainly of water with some organic contaminants, particularly if performed catalytically.

For PCB's, chlorinated hydrocarbons and pesticides, cement-kiln incineration and incineration at sea are both promising techniques and should be further developed, although they are at present not universally accepted.

Microwave plasma arc techniques have potential and development work is presently underway, mainly to demonstrate their effectiveness to public authorities.

(b) Safety and residuals. Most thermal techniques have the potential to create new toxic materials or to emit the ones originally present if operating conditions are not properly controlled. Critical factors are temperature, residence time, mixing and air supply. If control is poor or if some malfunction is not corrected quickly, many have the potential to distribute hazardous components over a large area.

Provision of afterburners, to ensure complete combustion, can help safeguard against this.

The burning of wastes containing halogens and sulphur will produce halogen acids (e.g. HCl) and SO₂. If there is insufficient hydrogen in the burning zone, pure halogens may be emitted, e.g. Cl₂. Nitric oxide will be formed in high temperature incinerators. Gas scrubbing equipment will remove most of the halogen acids and SO₂, but only part of the nitrogen oxides. Catalytic converters would be needed to remove nitrogen oxides completely. These are rarely installed, but scrubbing facilities are usually required if halogenated wastes are incinerated.

All thermal treatment processes require a high level of operational control and monitoring of gaseous emissions.

Solid residues and scrubber effluents do not normally present disposal problems, although they may require costly treatment. Some precipitated flue dusts, however, may contain high levels of toxic metals such as cadmium and lead, while incinerator ash may contain other toxic metals. Dry scrubbing procedures are being developed.

(c) Impacts. If properly controlled and monitored, the environmental impacts may be restricted to a) visual impacts; and b) the consequences of the traffic of hazardous material carriers to and from a plant.

If control is poor or if something breaks down, odorous and possibly corrosive or toxic emissions may be released from the stack.

Little information is recorded and available on the health impacts either on process workers or adjacent communities. Occasionally, there have been accidents at facilities, e.g. explosions (mainly in the pretreatment or shredding area), which have injured process workers, but not enough statistics are available for generally applicable comment to be made.

Public perception depends to an extent upon the marketing approach used. Bad marketing in the case of one cement kiln project in Canada (see Appendix C) led to implacable public opposition to the project. In other cases, odorous or visible, coloured emissions from stacks may produce complaints. This depends heavily upon local circumstances. Virtually all thermal treatment processes have the potential to be bad neighbours.

(d) Costs. Thermal treatment is at the expensive end of the treatment/disposal spectrum. Limited information is available upon what some existing facilities charge their customers:

U.K. (1981 prices charged)	<u>\$/tonne</u>
Bulk liquids (high CV, low contamination)	0 - 40
Bulk aqueous wastes (low contamination)	100
Bulk halogenated wastes	80 - 700
Bulk or drummed solids	90 - 1800
Incineration at sea	130 - 190

(Source: DOE submission to House of Lords, 1981)

<u>Denmark</u>	<u>\$/tonne</u>
Chlorinated liquids (subsidized)	up to 380

(Source: as above)

Federal Republic of Germany (Bavaria)

Specimen charge (subsidized) 84

(Source: as above)

Federal Republic of Germany

range 70 - 420

mean 186

Capital cost \$12.6M

Operating cost \$ 4.6M/a

Throughput: liquids 16,500 tonnes/annum

solids 10,000 tonnes/annum

10-17% of capital cost was for scrubbing devices

20% of running costs for scrubbing devices.

(Source: NATO - CCMS Conference, Washington,
October 1981)

Norway

Incineration in cement kiln, PCB's \$ 800/tonne

(Source: NATO - CCMS Conference, Washington,
October, 1981)

2.2 Individual assessment

2.2.1 Open pit/open burning

Liquids and solids have been handled in the past using these techniques, including tars and sludges.

Its performance in completely detoxifying chemicals is dubious because very little control is exercised over temperature, residence time or air supply. They have been used to reduce hazards from some explosives e.g. nitrocellulose.

Safety is dubious because gaseous residuals may contain unaltered feedstock or new compounds, possibly more hazardous; expert control is needed but monitoring is difficult due to the unconfined nature of the process. There is no control over emissions of acidic gases like HCl, SO₂.

The structures are fairly small, but the operation may produce sooty emissions and detectable odours. It is generally a rather uncontrolled, uncontrollable and unsatisfactory facility.

2.2.2 Multiple chamber

Multiple chambers are not suitable for liquids, sludges or tars because solids are burnt in the first chamber and then gases and gaseous products in the second chamber.

They are however considered able to destroy phenolic resins, epoxy resins, acrylic resins and PVC (Powers, 1976).

2.2.3 Multiple hearth

Multiple hearth techniques are suitable for solids, liquids, tars, sludges and gases. Liquids must however be combustible. A vortex burner is more effective for liquids needing supplementary fuel.

Temperatures of up to 1000°C can be achieved, so creating an environment suitable for destroying some halogenated organics. If the gases run counterflow to the solids, the gases may reduce in temperature to as low as 300°C and carry many odiferous gases with them. Afterburning should be considered in such cases.

2.2.4 Rotary kiln

A rotary kiln is versatile, especially if afterburners are fitted. It can then handle solids, liquids, gases and drummed materials.

If scrubbers are fitted this process can cope with virtually all hazardous organic chemicals, including those requiring supplementary fuels. Temperatures up to 1600°C have been achieved (special refractory liners needed). They have been used to dispose of obsolete munitions (Powers, 1976). The rotary kiln represents proven technology, and is in regular use for hazardous wastes. However, as in all incinerators, a high level of monitoring and operational control is needed since high concentrations of HCl, SO₂ or NO_x may escape if scrubbers are not fitted or fail to work. Ash and flue dust are generally acceptable for landfill.

2.2.5 Fluidized bed

This process can cope with solids (suitably pulverized), liquids and gases, but not drums. Most applications are for sludges and slurries. The removal of inert residues from the bed material may sometimes be a problem.

Temperatures of up to 1100°C can be achieved but are limited by the softening point of the bed material. However this is high enough to cope with most hazardous organic chemicals.

2.2.6 Liquid combustion

For liquid combustion, it is necessary that the liquid feedstock must be pumpable and atomizable; as a result blending and pre-heating facilities may be necessary so that viscous liquids can be handled. Care must then be taken that blending and heating do not in themselves cause any unwanted reactions such as polymerization in the feed system. In this process temperatures in the 1200-1450°C range can be achieved so that most chemical contaminants can be destroyed. Vortex-type burners have the highest heat release capabilities and may therefore be preferred.

A liquid combustion unit can be operated intermittently, whereas most other types are best suited to continuous operation.

2.2.7 Molten salt incinerators

Molten salt incinerators are still in the development stage. They may be used mainly when the feedstock is applied in powdered form.

High temperatures may be achieved and therefore pesticides can be broken down pyrolytically, or oxygen can be injected to give complete oxidation.

2.2.8 Incineration at sea

Incineration at sea can cope with solids and liquids including chlorinated organics, pesticides and PCB's, vinyl chloride, epoxy resin, and glycerin intermediates. Agent Orange has also been successfully destroyed.

Since it is remote from centres of population, it requires no gas scrubbing. Its mode of operation while the ship is at sea and in motion ensures rapid dispersion and dilution of acidic stack gases. There has been no evidence of the emission of unburnt feedstock.

This is a technique, however, that is not universally accepted despite the enormous buffering capacity of the oceans. The Oslo/London convention requires that if incineration on land is possible, disposal at sea should be forbidden.

2.2.9 Incineration in cement kilns

Liquids and tars have been burnt using cement kilns.

Chlorinated organics and PCB's have been successfully destroyed and it is likely that heavy metal contaminants will be bound chemically in the cement clinker.

It is recommended that samples should be injected directly into the flame envelope to ensure complete destruction (Neff, et al., 1977). A maximum loading of 0.4% w/w chlorine relative to clinker production is recommended, otherwise clogging of dust extraction equipment may occur. An increased supply of air is needed compared with normal cement making. Destruction of chlorinated organics have been rated at greater than 99.99%. The solid residues produced are the cement clinker and slightly increased production of kiln dust. No information is available on the leaching properties of either, but the clinker is expected to have the potential of binding heavy metals in a very stable silicate form. Operators should have extra training for this process in order that the system is operated to meet the required standards.

One advantage is that existing structures may be used so that no further environmental impact should be expected by new construction.

Some problems have been experienced in Ontario due to poor public relations. (See Appendix C).

2.2.10 Calcination

The methods for materials handling depends upon the type of plant since open hearth, multiple hearth, rotary kiln and fluidized bed systems can all be used.

The process may generally be applied to sludges and slurries with a high inorganic content. Typical feedstocks are water treatment plant sludges.

Temperatures achieved are usually in the range 650 - 1100°C (up to 1400°C) so it has the potential for the disposal of pesticides, PCB's and halogenated organics. Residence times, however, are usually long (greater than one hour) so that most organics would be expected to be destroyed. Heavy metals are bound into the solid matrix, with sand, clay or some other silicate being added, sometimes to help produce a vitrified product. This process has the potential for dealing with materials containing both organic and heavy metal contamination. The solid residues generated may be either granular or vitreous.

So far, there is no reliable information available on costs.

2.2.11 Pyrolysis

Solids, liquids and tars can be handled using pyrolytic systems; however the feedstock should consist mainly of organics.

It cannot yet be considered an established process for hazardous chemical destruction, although it has potential for the pyrolysis of PCB's prior to incineration, which may reduce the overall fuel requirements for PCB destruction.

Use of this process without afterburners would create a potential for the release of the unaltered PCB or of newly created compounds.

Temperatures of only 500 - 800°C are achieved in the absence of air indicating that complete destruction of organics is not achieved. In fact new compounds may be created. The process has potential for the destruction of hazardous chemicals if it is followed by full combustion. This combination may have lower overall energy requirements. This technology is not yet fully established for destroying hazardous materials and indeed may never replace direct incineration for this purpose.

2.2.12 Microwave plasma arc

Liquids and possibly fine powders are the most suitable for feedstock materials for application in the plasma arc process.

Organics and metal-organics have been destroyed using this technology, (e.g. PCBs, halocarbon compounds, pesticides, phenylmercuric acetate).

In this process residuals could be a problem, e.g. treatment of phosphorus-containing material may produce phosphoric acid as a residual (De Renzo, 1978). There are technical problems involved in scaling up the process and as a result only small quantities have been treated because of the difficulty maintaining the plasma in a larger volume. This is not yet an established technology, but studies are underway to develop and perfect this technique. Plasma arcs have been likened to low temperature incineration in which case there will be a need to demonstrate that unaltered feedstock, new toxic compounds or volatile heavy metals are not released in the process.

2.2.13 Wet air oxidation

The wet air oxidation process is suitable for aqueous solutions and suspensions with some organic contaminants.

Air is supplied, sometimes with catalysts and temperatures are in the range of 180 - 380°C with pressures of up to 69 bars (1000 psig) being reported.

The process is able to destroy cyanides as well as various propellants, explosives and munitions previously disposed of by open pit burning. It is also expected to be able to destroy a wide range of other hazardous organics present in fairly low concentrations. There is little information on its use for this purpose or on the residuals left in the aqueous stream.

The process should be regarded as having great potential for dilute aqueous waste streams.

There is little or no information presently available on costs.

3.0 Pretreatment processes

3.1 Biological (summary assessment)

- (a) Waste form. Except for composting, these processes are restricted to aqueous liquids. Aerobic processes are unsuitable to treat feeds over 1% solids. Anaerobic digestion can accommodate higher, more concentrated solutions as well as solids levels but may be somewhat slower.

Composting can process materials up to 50% solids. For many cellulose type materials this would be close to field capacity, (i.e. there would be little or no free liquid). If the solids content were any higher, the biological process efficiency would be limited by low moisture content.

Biological processes are designed to oxidize (or reduce) degradable organic compounds. This includes a number of hazardous organic compounds as well as some inorganics, e.g. cyanides. In some cases, heavy metals may be removed by precipitation/adsorption but could then cause disposal problems with the waste sludge. In general, aerobic processes are better able to acclimate to the removal of some hazardous components than are anaerobic processes.

Phenols, ammonia, cyanide, some pesticides, thiocyanate, sulphide, acrylic acid, methacrylic acid, benzyl alcohol, hydroquinone, glycols, formaldehyde, formic acid, hydrocarbons and acrolein have all been successfully removed by aerobic biological processes. However, the concentrations have been in the parts per million range or lower.

The aerobic processes most likely to be useful for hazardous waste treatment are activated sludge (and its variations), and trickling filters. However, they could not cope with more than low concentrations of hazardous materials. Their most likely application would be in cleaning up ground or surface waters which had become contaminated by some chemical accident.

Alternatively they might be used as a 'polishing' process after some other process had removed the major proportion of contaminants.

- (b) Safety and residuals. The inherent safety of biological treatment is good. Major accidents are unlikely to occur. Biological sludges will be produced as residuals. These represent a disposal problem, creating hazard if high concentrations of heavy metals or non-degraded hazardous organics are incorporated in the sludge.

Trained operators and good control are necessary, particularly if hazardous chemicals were involved, because biological processes are subject to intermittent failure for a variety of reasons. The presence of hazardous chemicals could result in such a failure if the process were inadequately controlled, thus causing them to be released in the effluent. If biological plants were used to treat hazardous chemicals, it would be necessary to ensure the use of a continuous effluent toxicity monitoring system.

- (c) Impacts. Structures may be unattractive and there may be noise and odour problems. These may be no worse than at many conventional sewage treatment works, but may demand that processes be enclosed and provided with odour-control equipment.

Airborne bacteria may create a health impact, but as yet there is little evidence of any increased risk, either to process workers or to adjacent communities. The presence of low concentrations of hazardous contaminants in the wastewater is unlikely to add to the risk.

Treatment of hazardous chemicals could create intensive public opposition if the public were not adequately informed ahead of time.

- (d) Costs. Variable. Biological processes are designed to be cheap ways of removing organic carbon (BOD) from wastewaters. Costs would normally be less than \$1.00/m³. However, the cost per tonne of sludge classified as hazardous could be very high.

3.2 Biological (individual assessment)

Activated sludge and trickling filters will be dealt with in this section. For composting see Land Treatment, in Section 4.1.

3.2.1 Activated sludge

It has been reported that low concentrations (up to 10 ug/l) of PCB's have been removed in an activated sludge system. However, it was noted that they were not destroyed but adsorbed on the sludge. In such a case, subsequent land treatment might allow biodegradation to occur (see 4.0 Land disposal).

Of the common variations, completely mixed systems are best able to withstand shock loads and so may offer the best option for effluents arising from chemical accidents. Operation as extended aeration would also help. Contact stabilization offers further protection in that only 10-15% of the biological floc is in the mainstream of waste flow and therefore exposed to a shock load of toxic wastes. The balance is held in a reaeration tank and released gradually to the contact tank. The main bulk of the sludge is therefore protected from any short term toxic effect.

A proprietary version of a completely mixed system is the PACT process. This involves the addition of powdered activated carbon to the mixed liquor. This may offer the best single possibility for biological processes to be used in this application. It has two advantages. Firstly, organic chemicals adsorbed on the carbon are retained in the system much longer, as the carbon is recycled with the sludge. The potential for poorly degradable compounds to be broken down is thus increased. Secondly, the carbon can be re-activated, in which process contaminants adsorbed on it will be thermally destroyed. However, the temperature of carbon reactivation may have to be elevated depending upon the toxic substance which must be destroyed. (See Thermal Processes Section IV.2.0).

3.2.2 Percolating filter (trickling filter, bacteria bed)

This process may have some application as it is generally less easily upset by toxic chemicals than activated sludge systems. Little information is so far available on the application of rotating biological contactors or fluidized beds for the treatment of hazardous chemicals. Aerated lagoons and stabilization ponds are not sufficiently controlled to be able to recommend their use for hazardous contaminants.

3.3 Physical/chemical (summary assessment)

(a) Waste form. These processes are normally used in addition to other processes in dealing with hazardous materials. The general objective of phase separation is to get the phase of interest into a more concentrated form, allowing the bulk of the other phase to be discharged or re-used. The concentrated phase can then be pretreated or ultimately disposed of more efficiently.

In the case of filtration, centrifugation, sedimentation and their many variants, the objective is to separate solids from liquids. This would be an essential accompaniment to some other treatment technologies, e.g. precipitation of heavy metals from solution as hydroxides, carbonates, etc. It is highly likely that one or other of these processes would be an essential component in a facility for dealing with hazardous chemicals.

Filtration and centrifugation are more applicable to fine particles or solids which do not settle well under gravity. However, for solids which do settle well, sedimentation is likely to be a cheaper alternative. Filtration and centrifugation require more energy than sedimentation. Forced evaporation is an even higher energy user but might be needed in the case of some soluble constituents. Natural evaporation from lined lagoons may be a cheaper alternative if land and time are available, and the components to be separated are not volatile.

Emulsion cracking and oil/water separation are regularly used in application with hazardous materials. Soluble oils (e.g. cutting oils) may contain additional hazardous components such as fungicides. Emulsion cracking followed by oil/water separation is a normal procedure for such materials. The same type of plant would be needed following component separation by liquid/liquid extraction.

Some form of phase separation should always be considered as a means of reducing the volume of residue sent to final disposal.

- (b) Safety and residuals. The inherent safety of most physical/chemical processes is good. There is less scope for catastrophic accidents during operation than with some chemical or thermal processes. There may, however, be hazardous gaseous emissions in air-stripping and steam stripping processes.

In most cases there will be a residue, generally a solid or a sludge, which will require disposal. This residue may contain hazardous components at a greater concentration than in the feed-stock to the process, and very careful handling and disposal would be needed.

The need for intensive technical control varies. In some cases, little attention is needed, whereas in others a great deal is needed.

- (c) Impacts. Most of the processes involve closed vessels and, except for gas stripping, involve only liquid and solid phases. There should therefore be few odour problems. However, as with all technologies, there may be unattractive visual impacts.

Effects on the environment and on the health of operators and local inhabitants should be minimal.

- (d) Costs. Costs will be highly variable. No specific information is available.

3.4 Physical/chemical (individual assessment)

3.4.1 Ion exchange

This is an established well-proven technique in widespread use. It has considerable potential for dealing with hazardous chemicals.

- (a) Waste form. Aqueous solutions, which must be free of suspended solids which would block the resin columns. (In addition to synthetic resins, some materials such as insoluble starch xanthate, and precipitated milk casein have been used as the ion exchange medium; also natural and synthetic zeolites.)

In theory any cations and anions can be removed. In the context of hazardous chemicals, cations of interest would be heavy metals, anions would be cyanides, halides, chromate. Also feasible is removal of acids such as carboxylic acids, sulphonic acids, phenols and some ionic surfactants. Ion exchange can be used as a pretreatment for some complexed cyanides. The use of certain cation exchange resins can break some of the complexes, retaining the metals on the column (for subsequent removal) and releasing the cyanide, for re-use or destruction).

- (b) Safety and residuals. This is a fairly safe process, and easy to control. Units can be designed (in some instances) needing very little operational control. Residuals are the aqueous effluent, spent regenerant solution, and occasionally spent resin. The aqueous effluent should be suitable for discharge if the process has been adequately controlled. The spent regenerant solution may be used to recycle hazardous but valuable components. Alternatively, it may require further treatment (e.g. precipitation) before disposal. The resins can in some cases irreversibly absorb some organics and this can cause a deterioration in performance. The disposal of loaded resins may require further treatment.

De Renzo (1978) has noted the possible use of ion exchange resins to increase safety factors during transportation of dangerous chemicals like thallium. Loaded on a resin, there is likely to be much less danger in the event of a transport accident, than if the thallium were transported as a solution.

- (c) Impacts. No adverse impacts are expected from this process. The units are usually not particularly large and do not generate odours or excess noise.

There should be zero health impact on process workers or on adjacent communities from the operation itself. The handling and disposal of spent regenerants and loaded resins, however, requires great care.

- (d) Costs. A costing exercise by EPA (ref. EPA, 1979) suggested costs of the order of \$20/m³ or more. This would, however, vary a great deal depending on circumstances.

3.4.2 Adsorption

In addition to materials in established use, i.e. various forms of activated carbon, a large number of others are used or have been proposed. These include alumina, silica, peat moss, peanut shells, coconut shells, ground rubber, sawdust, corn husks and expanded vermiculite. In some of these cases it may be that one of the main benefits is absorption of liquids. In the case of spillages this may make clean-up and handling problems very much easier.

The assessment below is principally for activated carbon, but is relevant to other adsorption materials.

- (a) Waste form. Dilute aqueous solutions, free of suspended solids are necessary for this process to be effective. This restriction applies mainly to activated carbon. For some other adsorbents, of a coarser grain size, the presence of some suspended solids may be less of a problem.

Some non-aqueous liquids can be dealt with, though these should also be free of suspended solids.

Carbon adsorption is effective for a very wide range of non-polar and high molecular weight organic chemicals. However, the more polar the compound and the more soluble it is in water (particularly for low molecular weight compounds), the less readily it is adsorbed on to activated carbon. High doses would be needed to achieve good removal of such chemicals. Examples would be alcohols and short-chain carboxylic acids. For most organic pesticides removal activated carbon would be effective. Some heavy metals and organometallics are also effectively removed by activated carbon as are many cyanides.

Peat moss is reported to be able to remove cadmium from solution, while ground rubber and sawdust have been shown to remove mercury and methylmercury from aqueous solution.

In activated carbon columns there often develops a considerable level of biological activity, which enhances the capacity of the process to remove organics.

- (b) Safety and residuals. There is little chance of sudden disasters with adsorption processes, and residuals can be thoroughly monitored before disposal. With activated carbon the residuals will consist of a solution, which will be suitable for discharge or for a subsequent treatment process, and spent carbon which can be thermally re-activated, with the loss of a small percentage of the carbon. The reactivation process itself destroys adsorbed organics if conducted at the right temperature (See Thermal Process Section IV, 2.0). If this option is taken then the process can be regarded as a type of thermal treatment in which the carbon is used as a pre-concentration step. Little information is available on the effectiveness of this adsorption/thermal destruction process for specific organics such as PCB's.

If thermal reactivation is not used then the spent carbon must be disposed of. Depending upon the nature and loading of adsorbed species, this may in itself require a high standard of disposal such as a secure landfill or some form of encapsulation/solidification.

- (c) Impacts. There should be minimal environmental impact if the process is properly controlled and residuals disposed of carefully.
- (d) Costs. Precise details will depend upon the specific application, but carbon adsorption is generally somewhat expensive.

Carbon adsorption is a proven, well established technology, suited to the removal of organics from dilute aqueous solutions. Its applicability to rehabilitation following chemical accidents is demonstrated by its selection as the treatment process for leachate from the Love Canal. Other adsorbents may have similar applicability, but there may be less full-scale operating experience with them. Some of these alternative substances may be particularly suitable as sorbents where there are handling problems with liquids. If hazardous constituents are adsorbed the disposal of the spent sorbent will be critical. Thermal treatment, secure landfill or some encapsulation/solidification process may be the most suitable.

3.4.3 Ultrafiltration/reverse osmosis

Both of these 'size-exclusion membrane' processes are in common use for some waste streams. Both require stringent quality control on the feedstock to avoid membrane fouling. Both must be tailored to the specific application, and to do so, proper pilot-scale studies are necessary. It may therefore be that less critical concentration techniques (e.g. evaporation, coagulation/sedimentation/filtration) while possibly more expensive in many instances, may be more appropriate.

Ultra filtration has been successfully used for an oily waste emulsion application so it is not as sensitive as reverse osmosis (S. Hruday 1983).

3.4.4 Dialysis/electrodialysis

Similar to ultrafiltration and reverse osmosis these processes are membrane processes and are in regular use for certain applications.

In dialysis, small solute molecules pass through a semi-permeable membrane from a concentrated to a dilute solution. Larger molecules and colloids remain in the concentrated solution. Thus two waste streams are formed, with an increase in total volume. The process is slow and expensive, and complete separation of components is not achieved.

Electrodialysis produces dilute and concentrated salt streams from starting concentrations in the 200-5000 ppm range (De Renzo, 1978). The synthetic membranes used are permeable only to either cations or anions. Passage of ions through alternating membranes is

encouraged by the application of an electric field to the system. Organic molecules and colloids do not pass through the membranes. Electrodialysis is therefore able to reduce the salt concentrations in a feedstream containing valuable organic materials. Again, two streams are produced from the initial feed.

3.4.5 Liquid/liquid extraction

Straightforward liquid/liquid extraction is based on the partition of a solute between two immiscible phases. The process relies on the solute having a greater solubility in the extractant phase than in the feedstock phase. A common example would be the extraction of phenol from an aqueous solution using an organic solvent. In practice most applications involve the removal of an organic solute from an aqueous phase into an organic phase. There are two major variations which extend the range of materials which can be extracted. Liquid ion exchange involves the use of extractants and chelants to allow inorganic chemicals (e.g. heavy metal ions) to migrate into the organic phase, from where they can be subsequently recovered in a more concentrated form.

In Liquid Membranes a water-in-oil emulsion is prepared. This is then placed in contact with an aqueous waste stream. Components from the waste stream can diffuse through the oil membrane into the aqueous phase in the interior of the emulsion droplets. The entire emulsion phase is then separated from the bulk aqueous phase, the emulsion is broken and the bulk aqueous phase with its extracted materials can be removed. This process can also be enhanced by the use of chelating agents, for instance, to increase metal mobility through the oil membrane into the aqueous droplets.

These processes in general are best operated on a continuous flow steady state basis and tailored to specific regular waste streams. Their efficiency could be adversely affected by the occurrence of surface active compounds in the waste. The type of solutes for which they are suited are certainly key constituents in many hazardous materials (e.g. phenols, heavy metals). In many cases practical problems of destabilizing emulsions have to be overcome and these processes may be best regarded as having potential for the future. They do offer some possibility of recovery and re-use of hazardous constituents.

The cost of the extractant can be high and require very efficient recycling. Furthermore, some extractants are slightly soluble and may exchange one pollutant for another.

3.4.6 Air stripping/steam stripping

These techniques are suitable for the removal from the liquid phase of dissolved gases and volatile organic materials. Air stripping is usually confined in practice to the removal of ammonia. Steam stripping is in regular use for removal of phenol, hydrogen sulphide,

mercaptans and other volatile constituents from industrial wastewater. These processes have potential application to aqueous wastes arising out of chemical accidents, steam stripping perhaps more so than air stripping.

If the stripped materials cannot be collected and dealt with separately the process may be suitable only for low concentrations, i.e. levels which can safely be released and dispersed in air. This limitation certainly applies with ammonia. Solutions with higher than a few hundred ppm would produce unacceptably high localized concentrations of NH_3 gas in the air.

3.4.7 Foam fractionation

Foam fractionation may have some limited application to hazardous materials. It is a technique which removes some surface active organic chemicals and suspended particles from aqueous solutions. By creating a very high area of gas/liquid interface (i.e. the foam), materials which accumulate at the interface are concentrated in the foam phase. Some suspended particles may also be removed by flotation at the same time. The technique has been applied to the detoxification of paper mill effluents. The chemicals removed by the foam are then in a more concentrated form and can be taken for final disposal by other techniques such as, say, incineration or wet air oxidation.

The use of foam fractionation as a pretreatment process may be an economical option if the bulk of the organics in a particular waste are left behind in the aqueous phase and are biodegradable. Expensive techniques like thermal treatment need then only be applied to the relatively small quantity of hazardous material so removed.

3.5 Chemical alteration (summary assessment)

- (a) Waste form. Chemical alteration processes are mainly applicable to aqueous solutions, slurries and some sludges. In some cases, other physical forms can be accommodated, such as tars. Solids, for instance cyanide-containing solids, would generally require to be dissolved before reaction.

A wide range of hazardous chemicals can be treated by some form of chemical alteration. In many cases, this will represent established, well-proven technology. However, considerable development work is continuing, particularly in oxidation/reduction techniques and hydrolysis techniques. Some of those which will be discussed are still at the proving stage.

Chemicals which can successfully be chemically treated include acids, alkalis, heavy metals, sulphides, chromates, cyanides, phenols, mercaptans, some pesticides and certain halogenated hydrocarbons. In general, though, most hydrocarbons, oils (except for emulsion breaking) and solvents are not suitable for chemical treatment.

- (b) Safety and residuals. Chemical alteration processes require a high level of control and monitoring. Care is needed in handling the feedstocks, many of which will represent the most hazardous waste streams likely to be encountered. Stringent quality control is needed at the point of acceptance of the material and in any mixing/blending operations prior to treatment. The treatment process itself may need a high level of operator skill and perhaps feed-back/feed-forward control systems. This is needed so that the operation is safe and so that the completion of the reaction can be assured.

In the case of continuous flow operations there may be a need for continuous toxicity monitoring of the effluent. In some cases, solid residues may themselves be hazardous and require very careful management.

- (c) Impacts. Given the correct standard of operational control and monitoring, there should be minimal impact on the health of plant workers or local communities. Many of the operations will involve open vessels, however, and there is scope for emission of odours, noise and visual impact. Because of the high hazard nature of many of the feedstocks for chemical treatment, there is a likelihood of intense public opposition.
- (d) Costs. Costs are highly variable, depending on the process, the feedstock, and the location. Where information is available it will be given in the assessment of individual processes.

3.6 Chemical alteration (individual assessment)

3.6.1 Precipitation. Precipitation is an established, proven technology and is very suitable for the removal from aqueous solution of most heavy metals. It can also be used for the removal of other toxic elements e.g. arsenic, beryllium. Precipitation is generally used in conjunction with a phase separation process such as sedimentation, and some sludge handling processes.

Precipitation as hydroxide, carbonate and sulphide are all in regular use. Hydroxide precipitation is the most common, with calcium hydroxide as the most common reagent to achieve it. For sulphide precipitation, both sodium sulphide and ferrous sulphide are used. Precipitation as chloride, sulphate or phosphate have some application, but only for a few specific metals.

- (a) Waste form. Most precipitation systems require aqueous solutions, but would be fairly tolerant of suspended solids already in the material.

Dissolved metals and sulphides are appropriate for this process. It has been suggested as a process for some pesticides, but that option is not well established so far.

- (b) Safety and residuals. If preceded by neutralization there is a need for care in handling acid and alkaline materials used for the neutralization process. Care must be exercised concerning their compatibility. If materials from different sources are being handled together: acids must be kept well away from materials containing cyanides or sulphides; and alkalies from materials containing ammonium salts. At any facility for handling these types of materials, regular checks should be run to ensure that there is no risk of toxic gases (hydrogen sulphide, hydrogen cyanide and ammonia) being released in response to pH changes. The operating system must be designed to minimize the risk of human error so that the wrong materials cannot be inadvertently mixed together.

Residuals are an aqueous effluent and a sludge or perhaps filter cake. The quality of the effluent will depend upon:

- a) The precipitant used;
- b) The level of process control;
- c) The presence in the waste of complexing ligands and high salt concentrations

In the case of hydroxide precipitation, the pH at which various metals have minimum solubility covers a broad range of pH values. As a result, if the material being treated contains a mixture of metals the pH cannot be optimized for all of them simultaneously. A compromise is therefore needed. This decision would be one of the process control options. It is generally straightforward to reduce the total concentration of heavy metals to less than 10 mg/l, individual metals to around 1 mg/l or less. With care, lower levels can sometimes be achieved. However, solubilities are increased by high ionic strength solutions and by the presence of complexing agents. These are used in a number of industrial processes and could seriously interfere with precipitation reactions.

With sulphide precipitation, very much lower metal concentrations can be achieved in the effluent. The equilibrium solubilities of most metal sulphides are orders of magnitude lower than their hydroxides. Since the free metal ion concentration is greatly reduced, the effect of complexing ligands is correspondingly reduced. However, the sulphide residual will have to be removed and the production of H_2S gas should be guarded against.

All precipitation processes produce a solid residue, containing the precipitated metals. These sludges can be dewatered and sent to landfill. Concern over subsequent release is regularly voiced though there is little evidence of that occurring in practice. An alternative procedure is to apply a solidification process to the aqueous sludge. This may provide a greater degree of immobilization. However, the suitability of disposing of solidi-

fied residues in non-secure landfill has not been established, and they may require the same standard of ultimate disposal as for non-solidified sludges.

- (c) Impacts. With the exception of visual structures such as mixing tanks, reagent hoppers, dewatering facilities, etc., the environmental impact would be minimal.

There is little evidence of any impact on the health of process workers or of adjacent communities.

- (d) Costs. Average U.K. costs (1981 prices) in \$/tonne

neutralization	20-70
sludge dewatering	10-24
neutralization, precipitation, dewatering	100 average

(Source: DOE Submission to House of Lords)

3.6.2 Neutralization

- (a) Waste form. Aqueous solutions, sludges, slurries and occasionally tars can all be neutralized, including all acids and alkalis, either organic or inorganic. Neutralization may precede, follow, or be an integral part of a precipitation process. In some instances it is possible to use one waste stream to neutralize another. Although generally applied to solutions, acid tars have been mixed with lime to neutralize them in situ after unsatisfactory land disposal had led to problems.

- (b) Safety and residuals. The neutralization reaction may liberate considerable amounts of heat and careful process control and monitoring is needed to ensure that this is not excessive and does not get out of control, resulting in fire or explosion. If operating on a continuous flow basis, process control may need to be sophisticated, involving feed-back and feed-forward controls over the addition of neutralizing chemicals.

Residuals will comprise aqueous effluent and perhaps a sludge, depending exactly on the nature of the material and the neutralizing chemicals used. In general the aqueous effluent may show an increase in the level of total dissolved solids. If precipitation is carried out simultaneously, the disposal of the sludge will need the same careful consideration.

- (c) Impact. Aqueous effluent may contain high concentrations of dissolved salts including sulphates. These can cause problems when discharged into concrete sewers with slow liquid velocities creating acid and corrosive conditions. In the case of discharge to land or to freshwater bodies, a generally high level of dissolved

solids could cause ecological problems if there is insufficient dilution.

No evidence has been found to suggest the possibility of adverse health impacts.

(d) Costs. Average U.K. (1981 prices) \$20-70/tonne.

(Source: DOE Submission to House of Lords)

3.6.3 Oxidation/reduction

There are several generic types of processes for oxidation and reduction of hazardous chemicals. One is the thermal oxidation techniques already considered. (Carbon adsorption with re-activation could also be regarded as a thermal oxidative technique.) The other main types are: chemical electrolytic/electrochemical, and catalytic/photolytic. In practice some of these methods may be combined.

Oxidation/reduction is well established as a means of dealing with some hazardous chemicals and already occupies a major position in the spectrum of processes in regular use for a number of wastes. Its use can be generally recommended for certain materials arising from chemical accidents. In practice, some variations have been tried and tested more than others. Alkaline chlorination of cyanides, for example, is well established as one of the primary means for destroying cyanides at licensed hazardous waste plants. There is still need for more development work and accumulation of operating experience in many of the processes. There are large differences in the capital and operating costs of the various alternatives.

In general, catalytic/photolytic technologies are less well proven than many chemical methods. However, they offer the promise of cheaper (or more efficient) complete destruction of some compounds than can be readily achieved by purely chemical means. They can be regarded as having great potential for the future. Electrolytic and electrochemical techniques are largely applicable to the removal of metals and may not be the most economical method in many other cases. They are best suited to fairly consistent feedstocks and may be more applicable to in-house use.

(a) Waste form. Most methods are applicable only to aqueous solutions or slurries. Solid materials such as some cyanide heat treatment wastes should be dissolved in water before treatment.

Chemical oxidation is effective for a wide variety of chemicals including cyanides, phenols, sulphides, mercaptans, some chlorinated hydrocarbons and pesticides. Oxidants in regular use include hypochlorites, chlorine, hydrogen peroxide, potassium permanganate and ozone.

The usefulness of ozone might be greatly enhanced if it were used in combination with photolysis and catalysis. For instance, while oxidation of free cyanide is straightforward (whether by ozone or say hypochlorite), the oxidation of metal-cyanide complexes is not as easy. Ferricyanide complexes are the most difficult of all. While ozone is more effective than hypochlorite for the oxidation of ferricyanides, it is still very difficult and costly in terms of ozone use. However, ozone with UV light is about thirty times more efficient.

A disadvantage of ozone in general is that it is prohibitively expensive for contaminants at concentrations of more than a few hundred mg/l. Furthermore, it often does not completely destroy the contaminant. Cyanide is usually oxidized only to cyanate. This may be acceptable for discharge in some circumstances but not in others. Hypochlorite oxidation, on the other hand, at least for free cyanides, can completely destroy the cyanide to nitrogen and carbon dioxide.

Similarly, potassium permanganate will oxidize cyanides to cyanates. It has been shown to degrade paraquat and diquat pesticides, but produce oxalates as one of the major product species.

Chromates are easily dealt with by chemical reduction, using sulphur dioxide, sulphites, ferrous sulphate or possibly metal turnings (e.g. iron). Chromates can also be reduced electrolytically, but this may be a more expensive option.

Chemical reduction using sodium borohydride (NaBH_4) is a technique that might be used with due caution and only in the hands of skilled personnel. However it shows some promise for the future. It has been applied to mercury compounds, organo-lead compounds and silver compounds allowing some recovery of the metal. It also has some potential, in combination with catalysts, for use in reductive dechlorination of pesticides. This application has been developed in a way that may allow use in the field by relatively inexperienced people and could be applied to contaminated materials and residues (De Renzo, 1978). This process cannot yet be regarded as proven.

Waste chemical oxidants e.g. chlorates and perchlorates can be chemically reduced using various mild reducing agents, e.g. iron filings, bisulphite, ferrous sulphate, thiosulphate. The methods of the electroplating industry, where one metal is used to displace another, might also be considered and could be useful for metal recovery (e.g. iron to reduce copper).

- (b) Safety and residuals. In nearly all cases, extreme care is needed in handling of oxidizing and reducing chemicals. The residuals produced may in themselves pose disposal problems and require great care in handling. In many cases an intensive level

of process control and monitoring is needed, both to avoid accidents and to ensure completeness of the reaction.

- (c) Impacts. Aqueous discharges may have an increased level of dissolved solids e.g. high chlorides from cyanide treatment by hypochlorite oxidation. This may have an environmental impact on the receiving waters.

The potential for accidents may be higher than for some other technologies, but no statistics are available. This could result in a health impact.

- (d) Costs. These are highly variable and there is little specific information available.

Cyanide oxidation by hypochlorite: \$390-780/tonne (U.K. 1981)
(depending upon cyanide concentration)
Same process in Denmark (subsidized) \$320/tonne

(Source: DOE Submission to House of Lords)

3.6.4 Hydrolysis

Hydrolysis is a technology which is in established use in many non-hazardous applications. It is particularly suitable for breaking down large organic molecules into smaller units. It can be applied to carbamate and organophosphorus pesticides, using alkaline conditions and elevated temperatures. However, there are some problems with the inability to predict what species may be produced and what their toxicity will be, as this is not a totally destructive process, but rather breaks up molecules into smaller units. It would be necessary to conduct pilot tests monitoring for toxicity in the treated stream.

At present, hydrolysis should be regarded as having potential for hazardous materials; but not as having proven applicability, except perhaps for a limited number of pesticides.

3.7 Solidification/encapsulation

This group of processes incorporates to varying degrees the two principles of altering the nature of a material to reduce its hazard and of permanently isolating the material from the rest of the environment. In some processes one will predominate, while in others it is not yet clear which will have the dominant effect.

Many of the processes are proprietary and full details are not available. Most have developed only within the last 10 years and have not been subjected to rigorous and widespread long term testing.

However, the technology involved in some of them is simple and it has been adequately shown that for some materials (particularly heavy metals) hazard can be reduced at least to the extent of other methods in common use, and that a considerable degree of long term protection may be provided.

3.7.1 Silicate-based processes

There are three main types of processes involved: those based on sodium silicate and a calcium source, those based on portland cement or other naturally cementitious materials, and those based on pozzolanic reactions between reactive siliceous materials (e.g. pfa) and a lime source.

In all cases they involve the conversion of an aqueous waste stream (solution, slurry or sludge) to a solid material as a result of the formation of hydrated calcium silicates. The solid may be a hard concrete-like material or a crumbly soil-like material.

The hazard of the material being treated may be reduced in two ways. Firstly, these may be a type of micro-encapsulation, where the hazardous material is incorporated within the mass of a solid cohesive matrix and thus screened from leaching processes. Secondly there may be specific chemical interactions in which components are precipitated to forms which are chemically very stable regardless of the physical state of the resulting material.

- (a) Waste form. Aqueous solutions, sludges, slurries and solids can be solidified. (Solids would have to be mixed into an aqueous slurry first.)

A wide variety of chemicals have been claimed to be suited to this process. However, only for inorganic chemicals, (mainly toxic metals) have these claims been widely accepted. It has not yet been established that organic chemicals can be either successfully fixed, or successfully prevented from interfering with the fixation of metals. Further long term evaluation and development may show whether this is possible.

- (b) Safety and residuals. The processes are essentially low technology involving simple blending and mixing procedures, and low temperatures. The only residue should be the solidified product. In a very few instances the processed waste has failed to solidify for reasons unknown.

Accidents during the process itself would only be likely to occur if, for example, technical control allowed incompatible materials to be mixed, resulting in excessive heat generation or the evolution of hazardous gases.

It is not yet widely accepted that the products can be safely disposed of in non-secure landfill. Until further widespread,

long term assessment can show that this would be safe, the treated material should be subjected to the same controls as hydroxide and sulphide sludges from conventional precipitation processes.

Control and monitoring should ensure that the product conforms to some performance specification. At present there is no universal agreement on standardized leach testing, but there is a great deal of research activity and discussion at the international level.

- (c) Impacts. Dust problems may be a problem during mixing and there have been some instances of odour complaints. However, if the processes were to be used exclusively for inorganic wastes environmental impact should be minimal.

Where a crumbly soil-like product is formed, occasional dust problems have been reported. Again, process control could probably eliminate this problem.

No evidence is available indicating adverse health impacts on process workers or adjacent communities.

- (d) Costs. U.K. costs (1981 prices):

<u>range (\$/tonne)</u>	<u>% of sales</u>
4-14	20.7
16-24	33.8
26-34	14.9
36-44	18.8
46-54	2.3
> 54	9.5

This produces an average cost per tonne of about \$30.

(Source: Evidence given to House of Lords Committee by industrial operator)

U.K. data given to House of Lords by the Department of Environment (1981 prices) suggested that costs in fact may range up to \$200/tonne or even more for some wastes.

3.7.2 Organic polymer processes/thermoplastic processes

The three organic-based processes are considered to have limited application to hazardous chemicals at present.

None incorporates any chemical binding of waste components. Rather, they rely on the physical separation of waste components from the environment.

The organic polymer processes normally operate at room temperatures. With aqueous materials, therefore, water is either incorporated into the solid matrix, or is excluded and may still need some sort of processing.

Thermoplastic processes involve heating to temperatures considerably over 100°C and so involve the evaporation of any water present. Additionally, because of the high temperatures involved, there is a fire risk if solvents or oxidizing materials (e.g. nitrates) are present. Encapsulation processes require the material to be presented in a dry powder form.

None of these processes has been evaluated in full-scale use for a wide range of hazardous chemicals. In view of this, and of the very high costs involved, they are thought to have only very limited application at present, particularly in the case of chemical accidents.

3.7.3 Vitrification

This process could be regarded as an adaptation of calcination (see 2.2.11). Materials are fused with silica to form a glass. In order to get the material to a state ready for vitrification, it will have undergone something akin to high temperature calcination. Water and organic materials will have been evaporated and burnt off, leaving the inorganic residue.

As a glass, the product is expected to have good resistance to leaching.

However, the process is known to be very expensive and consequently has not been applied to a large range of hazardous chemicals. While it is considered to have potential technically, particularly for immobilizing metals, it is not at present expected to be particularly suitable for use in chemical accidents.

Neither vitrification, nor the organic processes, represent established technology, though they may in the future. Silicate-based, ambient temperature processes have been used widely enough to be regarded as having a significant place in the overall spectrum of suitable technologies.

4.0 Land/sea disposal systems (summary assessments)

The land, sea and air are the ultimate repositories for all residuals from any treatment processes.

For residuals deposited on the land and in the sea, there are various options as to the exact techniques used.

- (a) Waste form. Solids, liquids, sludges, slurries, tars and drummed materials can all be handled by some form of land or sea disposal.

sal. If liquids are disposed of to land, care is needed to see that a proper balance is kept between liquid and solid inputs or that adequate arrangements are made for the collection and disposal of excess leachate. In sea disposal systems, care is needed that sufficient dispersion and dilution of liquids will occur and that drummed solids are not deposited in such a way that they could find their way ashore or to shallow coastal waters.

Chemically, land and sea disposal systems are fairly tolerant but their tolerance is open to abuse, and there is a need for skill and reasoned judgement in considering a particular application and location. To some extent the suitability of land/sea disposal for a particular waste is site specific.

A wide range of chemicals can be disposed of to land and, to a lesser extent, to sea. There are many examples of the successful applications of land treatment for waste oils in California, U.S.A. It depends for its success on a suitable dry climate.

However, certain kinds of hydrocarbons, oils, solvents and large quantities of concentrated cyanides, heavy metals and toxic organic chemicals are not suitable for land disposal. Alternative methods, or pre-treatment, should be used for these materials.

Many materials are prohibited for ocean or sea disposal by international agreement. Precise definitions of substances are very important under these circumstances.

- (b) Safety and residuals. There may be possibilities with land disposal, of incompatible chemicals contacting each other, resulting in explosions or release of hazardous gases. However, with proper technical control the risk of such an occurrence can be minimized. With both land and sea disposal the main risk is in the longer term. In both cases the legacy is likely to be elevated levels of some potentially hazardous chemicals. The nature and extent of these elevated levels has not been fully researched, nor, in the case of land disposal, has there yet been widespread debate on the degree of land contamination which is acceptable. To some extent this has occurred for sea disposal. In both cases, though, intensive monitoring is needed.
- (c) Impacts. In land disposal systems, large areas of land may be involved and there is a possibility of visual impacts and release of odours. In addition, ground and surface water contamination is a major risk and there are many documented cases of this occurring at poorly run sites. There is, however, very little evidence of adverse environmental or health impacts from properly run sites where adequate preparation and monitoring have been practised. Nevertheless, there remains the possibility of environmental and health impacts as a result of post-closure activi-

ties, and it is of great importance that monitoring and restrictions on land-use continue long after the closure of sites accepting hazardous chemicals.

Similarly with sea disposal, if properly carried out in accordance with the Oslo and London conventions, there should be little adverse impact on the environment or on public health. However, there have been cases of irresponsible disposal leading to drums of highly hazardous materials being washed ashore onto busy holiday beaches. Some of this material of course may have resulted from shipwrecks and loss of deck cargo in storms.

As with all treatment/disposal technologies, a high standard of operation and management is essential.

Public perception of land disposal is almost invariably antagonistic. For sea disposal this is less so.

- (d) Costs. Limited data, where available, will be given in the appropriate sections.

4.1 Sea disposal

Disposal at sea is controlled internationally by the London Convention of 1975. It identifies black-listed substances and grey-listed substances. Signatories to the convention undertake that they will not allow dumping of any black-listed substances at sea, other than in trace amounts, and that dumping of grey-listed substances will be vigorously controlled and monitored.

The current black-list is:

- organohalogen compounds
- organosilicon compounds
- carcinogens
- mercury and its compounds
- cadmium and its compounds
- persistent plastics
- oils loaded for dumping
- materials produced for biological and chemical warfare.

The grey list is:

- arsenic and its compounds
- lead and its compounds
- copper and its compounds
- zinc and its compounds
- cyanides
- fluorides
- pesticides not covered by the black list

acids
alkalis
materials with an oxygen demand

Grey list materials can only be dumped with a permit from the appropriate national body. The rules of the convention require that the secretariat be notified immediately if signatories are about to permit dumping of any material with more than 1000 mg/l of a grey list substance.

In practice, bulk materials containing readily degradable non-toxic organics and dilute acids and alkalis tend to be dispersed in shallow coastal seas. More toxic materials, such as cyanide heat treatment wastes, have been dumped in sealed drums in deeper areas of the ocean.

The first is an example of immediate dilution, hopefully to the point where no damage is caused to the marine ecosystem. The second is an example of initial isolation followed by, in theory, slow release. However, checking on the fate of such materials once they have been dumped is very difficult.

The oceans and seas undoubtedly have some potential to dilute, degrade and attenuate some waste materials. Sea disposal might be suitable for some materials arising from chemical accidents, but not those on the black list above and only limited concentrations and quantities of those on the grey list. Specific information on exactly what quantities and concentrations is not available.

4.2 Land treatment

Land treatment should be regarded as established technology for limited application for most kinds of oily materials. For more hazardous organics it holds great potential for the future in many countries. It is not suitable for large loadings of heavy metals unless a decision has been taken to allow long term contamination of the land being used. In some (European) countries the lack of available land makes this form of treatment generally unacceptable.

- (a) Waste form. Materials may be either solids or liquids and are either sprayed or spread onto the land with the soil being tilled to mix in the materials and provide aeration.

The process is fairly well established for oily sludges. Petroleum refinery sludges are regularly applied to land treatment and the oils are found to have decomposed within about three years. Most hydrocarbons are probably suitable for this technique. For many other organics the process is not yet proven but has demonstrated potential. This includes chlorinated compounds such as pesticides and PCBs. There is considerable promise that land treatment may be able to cope with limited concentrations of such

materials in future. Current research is developing strains of bacteria by gene implantation (especially Pseudomonas spp) that can degrade specific organic wastes.

So far, encouraging results have been obtained for 2,4,5-T, DDT, 2,4,-D, low chlorine-PCBs and pentachlorophenol. If these new strains can be adapted to land treatment the technique may prove particularly suitable for solids with a low level of contamination. Possibilities may develop for in situ reclamation of contaminated land, and rehabilitation of ecologically damaged areas resulting from chemical accidents.

Heavy metals may be adsorbed on to soil materials. However, if the objective is to maintain the land in a relatively uncontaminated state in the long term, inputs of heavy metals would have to be limited.

- (b) Safety and residuals. There is little information available on safe loading rates for oils and sludges. This depends very much on the climate and nature of the soil. There is, however, little opportunity for sudden catastrophies with land treatment. Monitoring must be geared to the long term to ensure that soil conditions continue to be suitable for degradation and also to ensure that there is no build-up of hazardous residuals.
- (c) Impacts. Little information is available on the effects of leaching by rainfall on land treatment.

Neither is there much information available on health impacts to workers or adjacent community.

- (d) Costs. These will be highly variable and site specific. Transportation costs for the wastes to the site are likely to exceed the cost of spreading and mixing.

4.3 Deep well injection

- (a) Waste form. Aqueous solutions are suitable for this type of disposal provided that the suspended solids are less than 10 ppm in order to avoid the blocking of pores and fissures.

Organic and inorganic chemicals which are completely soluble in water may be disposed of by deep well injection. The pH of the feedstock should be near neutral so that there is not risk of either corroding well casings or causing swelling of the clay minerals in the receiving strata. These are technical limitations. As the process is essentially one of permanently isolating waste in deep strata, the chemical nature of the dissolved material is not relevant, providing permanent isolation can be reasonably expected.

Another possibility could be permitting this type of disposal only for those wastes which give a sensory (taste or odour) early warning at concentrations well below their toxic threshold (S. Hrudey 1983).

- (b) Safety and Residuals. This technique involves no attempt to chemically alter the materials which are injected. It relies completely on permanent isolation and possibly some dilution. This concept requires some sort of political judgement as to whether this principle of disposal is acceptable. Once injected, the material is beyond any recall or remedial action, unlike the various forms of surface land disposal.

In order to meet the technical restrictions on this process, pre-treatment will probably be required such as neutralization, solids removal or skimming of separated organic phases. These processes in themselves may carry some degree of hazard unless adequately controlled.

The injection process itself carries some risk of surface spillage. Blow outs have occurred in some instances but it should be possible to prevent these with proper management.

A detailed knowledge of the stratigraphy of the site is necessary and well monitoring should be provided. In some countries, with a high density of gas and oil wells, this work may have been done already. However, if new injection and monitoring wells have to be drilled, the cost of the process may prove excessive.

- (c) Impacts. There should be little impact above-ground unless a blow out occurs. Possible underground impacts include leakage through cracks and fissures into strata other than those designated for disposal. The triggering of earthquakes is also a possibility as a result of the high pressures sometimes applied. By appropriate site selection the risk of such occurrences may be minimized.

Well contamination has been reported causing brackish waters to be forced into drinking water aquifers by injection pressures. Again, with site selection, operating and monitoring procedures, this could be avoided and there should be no impact on the health of process workers or adjacent communities.

The limited information available suggests that some public antagonism may occur if a careful public information programme is not prepared ahead of time.

- (d) Costs. The costs will be highly variable and very much dependent upon how much preliminary effort is needed for drilling, geophysical studies and preparation of monitoring boreholes.

Deep well disposal is an established technology for inorganic salt solutions. It is not, however, recommended as having wide application for the disposal of hazardous materials particularly if alternatives are available, since corrective action would be extremely difficult if leakage were to occur.

4.4 Secure landfill (containment/storage)

Standards for a secure landfill vary. However, they generally imply the ability to prevent the migration of any liquids generated within the site and to allow for its collection (and possibly treatment) should that prove necessary to avoid any leakage problems. Also implied is a level of operational control wherein precise records are kept of exactly where quantities and types of waste are deposited at the site. Also implied is an organizational structure whereby segregation of different types of waste can be arranged.

- (a) Waste form. Secure landfill is an acceptable disposal option for a large variety of materials. Solids, liquids, sludges, slurries and tars can be successfully disposed of, as can some drummed materials.
- (b) Safety and Residuals. If liquids are to be disposed of their quantity should be monitored carefully so that the containment capabilities of the site are not exceeded. Similarly, clean water inputs to the site, such as rainfall should also be carefully monitored and, where possible, excluded.

The major concern with a secure landfill is, of course, leachate. The term secure here implies that no leachate (liquid or gaseous) is permitted to escape.

If no leachate escapes then containment is achieved. To prevent leachate there are some techniques which may be employed:

- build landfill in an arid location with no rainfall or groundwater
- do not deposit liquid wastes
- control infiltration of clean water
- provide drainage to "catch" any unavoidable leachate
- line the facility with a very low permeability material (plastic or clay).

Although a wide variety of chemicals can be disposed of in secure landfills, certain chemicals such as explosives should not be landfilled. Similarly, solvents and burnable organics should not be landfilled. Certain classes of chemical should be kept apart, possibly by means of a cell system of impermeable berms. Acids and alkalis should particularly be disposed of at different points in the site, and it would be preferable if neutralization were carried out beforehand. Arrangements should be made to en-

sure that sulphide materials cannot come into contact with strong acids. Any materials containing appreciable amounts of cyanides should be pretreated before disposal. In general, secure landfill is not expected to involve any subsequent alteration of the materials deposited. Pretreatment of the deposited materials should therefore be encouraged.

- (c) Impacts. The technique relies purely upon the concept of permanently isolating hazardous chemicals from the rest of the environment. This principle involves a long term burden of monitoring the integrity of the system to enable responsible authorities to enforce control of leachate or gas migration. Without extensive pretreatment, a secure landfill provides no possibility of leaving anything but a highly contaminated piece of land with little or no potential for future use. Even if the external impact is negligible, this may be considered an unacceptable legacy.

An intensive level of operational care and monitoring is necessary. Given this, the external impact of the operation should be negligible. However, the options available for future land uses may be severely limited. Secure landfill of hazardous materials are really only practical in states where a system of land use control exists. This should include a system of checking in detail previous land-use activities before giving a permit for any proposed new use. Unless this is done an old hazardous site may emerge as a health threat. This could occur even if the operational standards of the landfill were high while it was active.

Given a high standard of operation, monitoring and land-use registration, there would be no health impacts on site workers or on adjacent communities. Public perception of secure landfill is likely to be antagonistic. Previous proposals have often met with intense opposition.

- (d) Costs. No data is available but the cost is likely to be high, perhaps comparable with co-disposal landfill.

4.5 Non-secure landfill

In this case it is implied that normal good practice will minimize or delay the escape of leachate but that the steps taken to control leachate migration are not as intensive as in the case of the secure landfill (containment site).

Only in certain circumstances (inert substances) could this option be recommended. There would need to be an assurance that large volumes of leachate containing hazardous contaminants would not be released, or that there were a sufficiently large unsaturated zone beneath the site for some guarantee to be given that attenuation would

reduce hazardous components to acceptable levels before reaching an aquifer. An alternative would be if migration were into a brackish or saline aquifer with no economic value, and it could be shown that by the time the liquid reached any ecosystem it had been sufficiently diluted and attenuated.

Unsaturated zones do have some ability to attenuate many contaminants such as heavy metals and degradable organics. However, this ability is highly variable, site specific and as a result poorly quantified. Similarly, dilution can occur in aquifers, but again, quantitative predictions are difficult.

This technique may be best suited to particularly dry countries, for dry hazardous materials, such that the potential for leachate production is negligible. Under these circumstances, however, the technique would be purely one of permanent isolation, and there would be little or no expectation that the hazardous nature of the materials would be reduced in the long term.

In a report published by the U.K. Government ("Cooperative Programme of Research on the Behaviour of Hazardous Wastes in Landfill Sites, HMSO London 1978) it is concluded that proper selection and management of landfill sites is more important for the management of hazardous wastes than is the technical containment and groundwater leachate described above. (Personal communication, E.E. Finnecy, Environmental Safety Group, Harwell, U.K.).

4.6 Co-disposal landfill

This process involves the disposal of industrial (including hazardous) wastes mixed with domestic refuse. In some circumstances this can be a very acceptable method of disposal. Research has shown that the environment provided by decomposing refuse may be very suitable for the breakdown and attenuation of many industrial waste components.

The ideal solution is one where refuse breakdown has reached a stage of equilibrium between acid and gas production. The steady state environment within the refuse while still anaerobic is then characterized by a neutral or slightly alkaline pH and low levels of BOD and fatty acids. Several mechanisms then act to reduce the hazardous nature of many chemicals:

- the refuse has a capacity to absorb liquids
- the refuse has a capacity to neutralize acids and alkalis
- some organics, including phenols, are degraded biologically
- heavy metals are precipitated and adsorbed on refuse components.

However, in the latter case, it should be noted that under anaerobic conditions the degradation process may depress the pH causing the heavy metals to be released and dissolved. Such dissolved

metals may then be chelated by the organic ligands present and transported through the system into the environment. Metals chelated in this way are unlikely to get adsorbed by the refuse components or the soil (Knox and Jones 1979).

- (a) Waste form. The types of chemicals for which the technique is suitable include acids and alkalis, a wide range of inorganic chemicals, including heavy metals, readily degradable organic chemicals and low concentrations of some slowly degradable chemicals such as some pesticides and cyanides. Materials containing more than traces of cyanides should not be landfilled.

The ability of a co-disposal landfill to cope with oils and solvents is not well demonstrated, they may adversely affect landfill degradation processes, and there are alternative methods available for their disposal, e.g. incineration. Explosives and any high inflammable materials should not be landfilled without pretreatment. As a result the disposal of predominantly organic liquids such as oils and solvents is not recommended.

- (b) Safety and Residuals. The safe operation of a co-disposal landfill facility requires a level of operational control and monitoring at least as great as that required for secure landfill. As well as monitoring, to ensure that there is no leakage through leachate of hazardous chemicals away from the site, it is important to know that normal landfill degradation processes are continuing. This is to ensure that there is no build-up of hazardous chemicals within particular areas of the site, and to monitor the progress of hazardous waste immobilization/degradation. If the monitoring and control are inadequate, there is a danger of exceeding the capacity of the refuse to accept hazardous chemicals. This could lead to irreversible changes. The landfill might then revert to being essentially a secure landfill offering only permanent isolation/storage of hazardous chemicals rather than a combination of isolation and chemical alteration.

- (c) Impacts. If operated and monitored correctly, co-disposal landfill should have no adverse environmental impacts outside the site. Clearly, large areas of land may be involved, up to several hundred hectares, and the original nature of the land will be permanently changed. In some cases, this could be a positive, rather than negative, impact; in many countries voids are being created at a faster rate than they are being consumed, due to various types of mineral extraction. Sand and gravel pits are of course man made voids which should not be filled with any refuse, toxic or otherwise. Clearly the porosity of the soil (sandy) would be such that leachate migration would be guaranteed to occur, in turn polluting the groundwater. Co-disposal landfill offers the promise of land reclamation. Loadings of industrial refuse and final restoration standards could be

designed such that, ultimately, society is not left with a highly contaminated area and does not have to maintain a perpetual care programme.

The capacity of co-disposal to accept hazardous chemicals has not so far been adequately quantified. However, it has been found in some cases that leachate quality shows no evidence of hazardous contaminants.

Until such time as the many interactions are better quantified, it is recommended that co-disposal only be practised at sites where collection and treatment of leachate are possible. Otherwise, in the event of serious leachate contamination by hazardous chemicals, remedial action would be extremely expensive and might come too late to prevent serious damage to the external environment and threaten human health.

At a properly run co-disposal site, there would be no health impacts upon either site workers or the adjacent communities. However, public perception of co-disposal landfill is generally antagonistic. There appears to be no differentiation in the public eye between secure landfill, co-disposal landfill and crude dumping. There is a tendency for the public to assume that sanitary landfill of domestic refuse is free of problems while co-disposal of industrial and domestic wastes will be full of problems.

(d) Costs. U.K. (1981 prices) up to \$60/tonne.

There may be a list of materials that should be considered as entirely unsuitable for landfill disposal except in very small quantities. Such a list might include:

- highly flammable waste
- sensitive explosive materials
- materials which react with water (or dilute acid) to produce hazardous gases
- concentrated acids or alkalis
- material with a low odour threshold
- strong oxidizing wastes

Furthermore, there are certainly certain wastes which may be deposited in landfills only with the utmost of care. These include:

- any liquid wastes (to maintain the water balance in the landfill)
- drummed or contained wastes
- incompatible (with wastes already present) wastes due to possible undesirable reactions
- highly soluble but poorly degradable wastes.

4.7 Mineshaft disposal

Mineshaft disposal of liquids does not involve injection into porous strata, but rather uses the spaces of the mineshaft itself. The technique is in current use. If it can be shown that the mineshaft is geologically isolated and there is minimum risk to any aquifers or surface waters then the technique may be environmentally acceptable. It has the technical advantage over deep well disposal that minimal pretreatment of materials is needed, and that organic liquids can be accommodated. However, it suffers from the same objections, that it involves only isolation, and that control and remedial measures would be very difficult once the materials were deposited.

4.8 Permanent storage (sealed containers)

This technique is practised in West Germany, where wastes are sealed in drums and stored in caverns in an underground salt mine. Wastes of different types are segregated. Complete records are maintained on the precise locations of all wastes, so that if recovery should prove economical or necessary in the future, the wastes can be retrieved. The following limitations are put on this system in Germany:

- No liquids are accepted;

- No thermally unstable materials are accepted;

- No materials having a high vapour pressure which could cause air pollution problems are accepted.

Given these restrictions, the technique is recommended, particularly for materials where there is some possibility of resource recovery in the future.

There is likely to be no adverse environmental impact, and no health impacts, provided that operational control and monitoring standards are high.

Public perception of the process has been antagonistic. The cost (1981 prices) is approximately \$74/tonne.

5.0 Discussion/conclusions

Many of the technologies assessed in this document are already in regular use for treatment/disposal of hazardous wastes. In particular the following processes are frequently offered commercially on a contract basis:

- incineration
- neutralization of acids and alkalis
- phase and component separation
- chemical oxidation
- chemical reduction
- silicate-based solidification
- secure landfill
- co-disposal landfill

In many areas, facilities may therefore be available which offer various combinations of these processes.

Within the limitations noted for each process, they can be recommended for application to materials arising from chemical accidents. In almost all cases the standards of operation and management will play as great a role as the intrinsic properties of the process itself. A well-run landfill, for example, may have less environmental impact than a badly run incinerator, even though incineration has the potential for rapid and complete destruction of hazardous chemicals.

Chemical accidents may generate a spectrum of materials quite different from those generated regularly as wastes. It is likely that there will be greater volumes of relatively pure chemicals, and greater volumes of contaminated earth and soil. In this case, if the volumes are very large, there may be little practical alternative to securing the site, at least as an interim measure.

There are some materials and chemicals for which disposal remains a problem or for which there are very few options available. The destruction of complexed cyanides remains difficult. For asbestos wastes there is little alternative to some form of land disposal securely bagged or in some isolated form. Solidification may offer one way of isolating the material prior to land disposal.

Many techniques are not yet established but show promise for the future. Two of the most promising for use in chemical accident applications are (a) development of bacterial strains for use in land treatment of toxic organic chemicals (or contaminated soils), (b) catalytically assisted processes for redox reactions.

For materials containing toxic metals, it does not yet appear that electrolytic/electrochemical techniques are easily applied to feedstock whose specifications may be incompletely known and whose quality is likely to be variable. However, if future developments allowed such materials to be treated there may be considerable scope for resource recovery from contaminated materials.

At this point in the document it is worthwhile differentiating between wastes which are difficult to dispose of for technical, toxic or hazardous reasons and those which are difficult due to legislative reasons. Some wastes appear in both categories.

In some countries it is now difficult, if not impossible, to find a legal disposal route. Under these circumstances the generators of such wastes are obliged to find illegal disposal practices (midnight dumping) or export the wastes to neighbouring, less regulated states. It is therefore essential that SOME legal disposal outlet MUST be available; otherwise we will inherit problems in locations and at times that will be unexpected and possibly result in chemical emergencies.

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VI. Appendices

Appendix A: Chemicals successfully treated by thermal techniques

Note: When these substances are mixed with other less toxic or hazardous substances, the requirements for destruction MAY BE REDUCED.

ORGANICS:

Acetaldehyde
Acetic Acid
Acetic Anhydride
Acetone
Acetone Cyanohydrin: oxides of nitrogen are removed from the effluent gas by scrubbers and/or thermal devices.
Acetyl Chloride
Acetylene
Acridine: oxides of nitrogen are removed from the effluent gas by scrubbers and/or thermal devices.
Acrolein: 1500°F, 0.5 sec minimum for primary combustion; 2000°F, 1.0 sec for secondary combustion, combustion products CO₂ and H₂O.
Acrylic Acid
Acrylonitrile: NO_x removed from effluent gas by scrubbers and/or thermal devices.
Adipic Acid
Allyl Alcohol
Allyl Chloride: 1800°C, 2 seconds minimum.
Aminoethylethanolamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.
Amyl Acetate
Amyl Alcohol
Aniline: oxides of nitrogen are removed from the effluent gas by scrubber, catalytic or thermal device.
Anthracene
Benzene
Benzene Sulfonic Acid: incineration followed by scrubbing to remove the SO₂ gas.
Benzoic Acid
Benzyl Chloride: 1500°C, 0.5 second minimum for primary combustion; 2200°F, 1.0 second for secondary combustion; elemental chlorine formation may be alleviated through injection of steam or methane into the combustion process.
Butadiene
Butane
Butanols
1-Butene
Butyl Acrylate n-Butylamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.

Butylenes

Butyl Phenol

Butyraldehyde

Camphor

Carbolic Acid (Phenol)

Carbon Disulfide: a sulfur dioxide scrubber is necessary when combusting significant quantities of carbon disulfide.

Carbon Monoxide

Carbon Tetrachloride: preferably after mixing with another combustible fuel; care must be exercised to assure complete combustion to prevent the formation of phosgene; an acid scrubber is necessary to remove the halo acids produced.

Chloral Hydrate: same as carbon tetrachloride.

Chlorobenzene: same as carbon tetrachloride.

Chloroform: same as carbon tetrachloride.

Creosote

Cresol

Crotonaldehyde

Cumene

Cyanoacetic Acid: oxides of nitrogen are removed from the effluent gas by scrubbers and/or thermal devices.

Cyclohexane

Cyclohexanol

Cyclohexanone

Cyclohexylamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.

Decyl Alcohol

Di-n-Butyl Phthalate

Dichlorobenzene: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Dichlorodifluoromethane (Freon): same as dichlorobenzene

Dichloroethyl Ether: same as dichlorobenzene

Dichloromethane: (methylene chloride) same as dichlorobenzene

1,2-Dichloropropane: same as dichlorobenzene

Dichlorotetrafluoroethane: same as dichlorobenzene

Dicyclopentadiene

Diethanolamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.

Diethanolamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.

Diethylamine: same as diethanolamine.

Diethylene Glycol

Diethyl Ether: concentrated waste containing no peroxides: discharge liquid at a controlled rate near a pilot flame. Concentrated waste containing peroxides: perforation of a container of the waste from a safe distance followed by open burning.

Diethyl Phthalate

Diethylstilbestrol

Diisobutylene

Diisobutyl Ketone

Diisopropanolamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.

Dimethylamine: same as diisopropanolamine.

Dimethyl Sulfate: incineration (1800°F , 1.5 seconds minimum) of dilute, neutralized dimethyl sulfate waste is recommended. The incinerator must be equipped with efficient scrubbing devices for oxides of sulfur.

2,4-Dinitroaniline: controlled incineration whereby oxides of nitrogen are removed from the effluent gas by scrubber, catalytic or thermal device.

Dinitrobenzol: incineration (1800°F , 2.0 seconds minimum) followed by removal of the oxides of nitrogen that are formed using scrubbers and/or catalytic or thermal devices. The dilute wastes should be concentrated before incineration.

Dinitrocresol: incineration (1100°F minimum) with adequate scrubbing and ash disposal facilities.

Dinitrophenol: incinerated (1800°F , 2.0 seconds minimum) with adequate scrubbing equipment for the removal of NO_x .

Dinitrotoluene: pretreatment involves contact of the dinitrotoluene contaminated waste with NaHCO_3 and solid combustibles followed by incineration in an alkaline scrubber equipped incinerator unit.

Dioxane: concentrated waste containing no peroxides; discharge liquid at a controlled rate near a pilot flame. Concentrated waste containing peroxides: perforation of a container of the waste from a safe distance followed by open burning.

Dipropylene Glycol

Dodecylbenzene

Epichlorohydrin: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Ethane
Ethanol
Ethanamine: controlled incineration; incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.
Ethyl Acetate
Ethyl Acrylate
Ethylamine: controlled incineration; incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.
Ethylbenzene
Ethyl Chloride: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.
Ethylene
Ethylene Cyanohydrin: controlled incineration (oxides of nitrogen are removed from the effluent gas by scrubbers and/or thermal devices).
Ethylene Diamine: same as ethylene cyanohydrin.
Ethylene Dibromide: controlled incineration with adequate scrubbing and ash disposal facilities.
Ethylene Dichloride: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.
Ethylene Glycol
Ethylene Glycol Monoethyl Ether: concentrated waste containing no peroxides; discharge liquid at a controlled rate near a pilot flame. Concentrated waste containing peroxides; perforation of a container of the waste from a safe distance followed by open burning.
Ethyl Mercaptan: incineration (2000°F) followed by scrubbing with a caustic solution.
Fatty Acids
Formaldehyde
Formic Acid
Furfural
Glycerin
n-Heptane
Hexamethylene Diamine: incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions.
Hexane
Hydroquinone: incineration (1800°F, 2.0 sec. minimum) then scrub to remove harmful combustion products.
Isobutyl Acetate

Isopentane
Isophorone
Isoprene
Isopropanol
Isopropyl Acetate
Isopropyl Amine: controlled incineration (incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions).
Isopropyl Ether: concentrated waste containing no peroxides; discharge liquid at a controlled rate near a pilot flame. Concentrated waste containing peroxides: perforation of a container of the waste from a safe distance followed by open burning.
Maleic Anhydride: controlled incineration: care must be taken that complete oxidation to nontoxic products occurs.
Mercury Compounds:(Organic): incineration followed by recovery/removal of mercury from the gas stream.
Mesityl Oxide
Methanol
Methyl Acetate
Methyl Acrylate
Methyl Amine: controlled incineration (incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions).
Methyl Amyl Alcohol
n-Methylaniline: controlled incineration whereby oxides of nitrogen are removed from the effluent gas by scrubber, catalytic or thermal device.
Methyl Bromide: controlled incineration with adequate scrubbing and ash disposal facilities.
Methyl Chloride: same as methyl bromide.
Methyl Chloroformate: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.
Methyl Ethyl Ketone
Methyl Formate
Methyl Isobutyl Ketone
Methyl Mercaptan: incineration followed by effective scrubbing of the effluent gas.
Methyl Methacrylate Monomer
Morpholine: controlled incineration (incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions).
Naphtha

Naphthalene

-Naphthylamine: controlled incineration whereby oxides of nitrogen are removed from the effluent gas by scrubber, catalyst or thermal device.

Nitroaniline: incineration (1800°F, 2.0 seconds minimum) with scrubbing for NO_x abatement.

Nitrobenzene: same as nitroaniline

Nitrocellulose: incinerator is equipped with scrubber for NO_x abatement.

Nitrochlorobenzene: incineration (1500°F, 0.5 second for primary combustion; 2200°F, 1.0 second for secondary combustion). The formation of elemental chlorine can be prevented through injection of steam or methane into the combustion process. NO_x may be abated through the use of thermal or catalytic devices.

Nitroethane: incineration, large quantities of material may require NO_x removal by catalytic or scrubbing processes.

Nitromethane: same as nitroethane

Nitrophenol: controlled incineration: care must be taken to maintain complete combustion at all times. Incineration of large quantities may require scrubbers to control the emission of NO_x.

Nitropropane: same as nitroethane

4-Nitrotoluene: same as nitrophenol

Nonyl Phenol

Octyl Alcohol

Oleic Acid

Oxalic Acid: pretreatment involves chemical reaction with limestone or calcium oxide forming calcium oxalate. This may then be incinerated utilizing particulate collection equipment to collect calcium oxide for recycling.

Paraformaldehyde

Pentachlorophenol: incineration (600° to 900°C) coupled with adequate scrubbing and ash disposal facilities.

n-Pentane

Perchloroethylene: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Phenylhydrazine Hydrochloride: controlled incineration whereby oxides of nitrogen are removed from the effluent gas by scrubber, catalytic or thermal device.

Phthalic Anhydride

Polychlorinated Biphenyls (PCBs): incineration (3000°F) with scrubbing to remove any chlorine containing products.

Polypropylene Glycol Methyl Ether: concentrated waste containing no peroxides: discharges liquid at a controlled rate near a pilot flame. Concentrated waste containing peroxides: perforation of a container of the waste from a safe distance followed by open burning.

Polyvinyl Chloride: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Propane

Propionaldehyde

Propionic Acid

Propyl Acetate

Propyl Alcohol

Propyl Amine: controlled incineration (incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions).

Propylene

Propylene Oxide: concentrated waste containing no peroxides; discharge liquid at a controlled rate near a pilot flame. Concentrated waste containing peroxides; perforation of a container of the waste from a safe distance followed by open burning.

Pyridine: controlled incineration whereby oxides of nitrogen are removed from the effluent gas by scrubber, catalytic or thermal devices.

Quinone: controlled incineration (1800°F, 2.0 seconds minimum).

Salicylic Acid

Sorbitol

Styrene

Tetrachloroethane: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Tetraethyl Lead: controlled incineration with scrubbing for collection of lead oxides which may be recycled or landfilled.

Tetrahydrofuran: concentrated waste containing peroxides; perforation of a container of the waste from a safe distance followed by open burning.

Tetrapropylene

Toluene

Toluene Diisocyanate: controlled incineration (oxides of nitrogen are removed from the effluent gas by scrubbers and/or thermal devices).

Toluidine: same as toluene diisocyanate.

Trichlorobenzene: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Trichloroethane: same as trichlorobenzene.

Trichloroethylene: same as trichlorobenzene.

Trichlorofluoromethane: same as trichlorobenzene.

Triethanolamine: controlled incineration (incinerator is equipped with a scrubber or thermal unit to reduce NO_x emissions).

Triethylamine: same as triethanolamine.

Triethylene Glycol

Triethylene Tetramine: same as triethanolamine.

Turpentine

Urea: same as triethanolamine.

Vinyl Acetate

Vinyl Chloride: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Xylene

Also according to R.S. Ottinger et al. (3), inorganic chemicals which may be disposed of (after indicated pretreatment in some cases) by controlled incineration are:

INORGANICS

Boron Hydrides: with aqueous scrubbing of exhaust gases to remove B₂O₃ particulates.

Fluorine: pretreatment involves reaction with a charcoal bed. The product of the reaction is carbon tetrafluoride which is usually vented. Residual fluorine can be combusted by means of a fluorine-hydrocarbon air burner followed by a caustic scrubber and stack.

Hydrazine: controlled incineration with facilities for effluent scrubbing to abate any ammonia formed in the combustion process.

Hydrazine/Hydrazine Azide: the blends should be diluted with water and sprayed into an incinerator equipped with a scrubber.

Mercuric Chloride: incineration followed by recovery/removal of mercury from the gas stream.

Mercuric Nitrate: same as mercuric chloride.

Mercuric Sulfate: same as mercuric chloride.

Phosphorus (white or yellow): controlled incineration followed by alkaline scrubbing and particulate removal equipment.

Sodium Azide: disposal may be accomplished by reaction with sulfuric acid solution and sodium nitrate in a hard rubber vessel. Nitrogen dioxide is generated by this reaction and the gas is run through a scrubber before it is released to the atmosphere. Controlled incineration is also acceptable (after mixing with other combustible wastes) with adequate scrubbing and ash disposal facilities.

Sodium Formate: pretreatment involves conversion to formic acid followed by controlled incineration.

Sodium Oxalate: pretreatment involves conversion to oxalic acid followed by controlled incineration.

Sodium-Potassium Alloy: controlled incineration with subsequent effluent scrubbing.

Further, according to R.S. Ottinger et al. (3), waste pesticide streams which may be subjected to ultimate disposal by incineration are:

PESTICIDES

Aldrin: (1500°F, 0.5 seconds minimum for primary combustion; 3200°F, 1.0 second for secondary combustion) with adequate scrubbing and ash disposal facilities.

Chlordane: same as aldrin.

DDD: incineration (1500°F, 0.5 second minimum for primary combustion; 2200°F, 1.0 second for secondary combustion) with adequate scrubbing and ash disposal facilities.

Demeton: same as DDD.

2,4-D: same as DDD.

Dieldrin: same as aldrin.

Guthion: same as DDD.

Heptachlor: same as aldrin.

Hexachlorophene: incineration, preferably after mixing with another combustible fuel. Care must be exercised to assure complete combustion to prevent the formation of phosgene. An acid scrubber is necessary to remove the halo acids produced.

Methyl Parathion: same as DDD.

Parathion: same as DDD.

Finally, according to R.S. Ottinger et al. (3), ordnance waste streams which may be subjected to ultimate disposal by incineration are:

ORDNANCE WASTES

Ammonium Picrate: incineration followed by adequate particulate abatement and wet scrubbing equipment.

1,2,4-Butanetriol Trinitrate: the current method of absorption in sawdust, wood pulp or fullers earth followed by open pit burning is feasible but unsatisfactory because of the NO_x evolved. Methods currently under investigation for minimum environmental impact include bacterial degradation and controlled incineration with afterburners and scrubbers for abatement of NO_x .

Chlorates with Red Phosphorus: incineration followed by effluent scrubbers to abate NO_x , P_4O_{10} , HCl , SO_2 and metal oxides.

Chloropicrin: incineration (1500°F , 0.5 second minimum for primary combustion; 2200°F , 1.0 second for secondary combustion) after mixing with other fuel. The formation of elemental chlorine may be prevented by injection of steam or using methane as a fuel in the process.

Copper Chlorotetrazole: controlled combustion employing a rotary kiln incinerator equipped with appropriate scrubbing devices. The explosive is fed to the incinerator as a slurry in water. The scrubber effluent would require treatment for recovery of particulate metal compounds formed as combustion products.

Diazodinitrophenol: incinerator is equipped with suitable afterburner or alkaline scrubbing systems for the abatement of the NO_x liberated.

Dipentaerythritol Hexanitrate: controlled incineration in rotary kiln incinerators equipped with afterburner or flue gas scrubbers.

GB (Nonpersistent Nerve Gas): incineration followed by adequate gas scrubbing equipment; chemical reaction with sodium hydroxide.

Gelatinized Nitrocellulose (PNC): controlled incineration in rotary kiln incinerators equipped with afterburners or flue gas scrubbers.

Glycerolmonoacetate Trinitrate (GLTN): current method of absorption in sawdust, wood pulp or fullers earth followed by open pit burning is feasible but unsatisfactory because of the NO_x evolved. Methods currently under investigation for minimum environmental impact include bacterial degradation and controlled incineration with afterburners and scrubbers for abatement of NO_x .

Glycol Dinitrate (DDN): controlled incineration in the scrubber equipped Deactivation Furnace incinerator (The Chemical Agent Munition Disposal System).

Gold Fulminate: controlled combustion employing a rotary kiln incinerator equipped with appropriate scrubbing devices. The explosive is fed to the incinerator as a slurry in water. The scrubber effluent would require treatment for recovery of particulate metal compounds formed as combustion products.

Lead 2,4-Dinitroresorcinate (LDNR): controlled combustion - the lead dinitroresorcinate is fed to the incinerator as slurry in water. The scrubber effluent requires treatment for recovery of the particulate lead oxide formed as a product of combustion; U.S. Army Material Command's Deactivation Furnace.

Lead Styphnate: controlled incineration - the lead styphnate is fed to the incinerator as a slurry in water. The scrubber effluent would then require treatment for recovery of the particulate lead oxide formed as a combustion product.

Mannitol Hexanitrate: incineration followed by an afterburner to abate NO_x , and cyclones and scrubbing towers for removal of metallic dusts and fumes.

Mercuric Fulminate: incineration (Army Material Command's Deactivation Furnace) followed by caustic or soda ash gas scrubbing. The mercury is removed from the scrubbing solution.

Nitrogen Mustards: incineration - combustion products are carbon dioxide, water, HCl and nitrogen oxides. The nitrogen oxides require scrubbing or reduction to nitrogen and oxygen before the combustion gases are released to the atmosphere.

Nitroglycerin: incineration - exit gases should be scrubbed in a packed tower with a solution of caustic soda or soda ash. (U.S. Army Material Command Deactivation Furnace).

Pentaerythritol Tetranitrate (PETN): The PETN is dissolved in acetone and incinerated. The incinerator should be equipped with an afterburner and a caustic soda solution scrubber.

Picric Acid: controlled incineration in a rotary kiln incinerator equipped with particulate abatement and wet scrubber devices.

Silver Styphnate: controlled combustion employing a rotary kiln incinerator equipped with appropriate scrubbing devices. The explosive is fed to the incinerator as a slurry in water. The scrubber effluent would require treatment for recovery of particulate metal compounds formed as combustion products.

Silver Tetrazene: same as silver styphnate.

Smokeless Powder: controlled incineration - incinerator is equipped with scrubber for NO_x abatement.

Sulfur Mustards: sulfur mustard may be dissolved in gasoline and incinerated using the U.S. Army Material Command's Deactivation Furnace (Chemical Agent Munition Disposal System). The combustion products are removed by alkaline scrubbing.

TNT: TNT is dissolved in acetone and incinerated. The incinerator should be equipped with an afterburner and a caustic soda solution scrubber.

Tear Gas (CN)(Chloroacetophenone): tear gas-containing waste is dissolved in an organic solvent and sprayed into an incinerator equipped with an afterburner and alkaline scrubber; reaction with sodium sulfide in an alcohol-water solution. Hydrogen sulfide is liberated and collected by an alkaline scrubber.

Tear Gas, Irritant: hydrolysis in 95% ethanol and 5% water followed by incineration and then by a caustic scrubber.

Tetranitromethane: open burning at remote burning sites. This procedure is not entirely satisfactory since it makes no provision for the control of the toxic effluents, NO_x and HCN. Suggested procedures are to employ modified closed pit burning, using blowers for air supply and passing the effluent combustion gases through wet scrubbers.

VX (persistent nerve gas): incineration followed by adequate gas scrubbing equipment.

Appendix B: Sources of listings of hazardous chemicals/materials

- a) UNITED NATIONS ENVIRONMENT PROGRAMME. International register of potentially toxic chemicals; published every 6 months.
- b) U.S. NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (1980). Registry of toxic effects of chemical substances.
- c) U.S. EPA. Regulations published under the Resource Conservation and Recovery Act of 1976. Regulations published in the Federal Register of May 19, 1980. These take a combined approach to defining hazardous materials. These are listings of specific chemicals, any of which would render a material hazardous. There are listings of specific industrial processes, whose residues are defined as being hazardous. Finally, for materials not covered by those lists, standard testing procedures are defined to allow a material to be classed as hazardous or non-hazardous.
- d) U.K. DEPARTMENT OF ENVIRONMENT (1981). Waste management paper no. 23. An Annex to the paper gives an extensive listing of hazardous chemicals, with some relevant information on toxicity, etc.

Appendix C

SITE SELECTION FOR FACILITIES

by P. Byer

1.0 Introduction

In addition to the need for appropriate treatment/disposal facilities, it is important to carefully select their locations. The choice of facility site can affect the risk of environmental and health damage, transportation costs, and facility design requirements (for example, landfill liner design should depend on the hydrogeology of the site). It is not surprising that in many countries hazardous facility siting is an important political concern, as a result of public outrage characterized by the "not in my backyard" syndrome.

This section briefly describes a suggested basic process to choose sites for hazardous waste facilities. The process attempts to identify sites that meet the needs for waste processing and disposal, while achieving an acceptable (and hopefully optimal) trade-off between economic, environmental and health impacts. The process is broken into four basic steps: 1) assessment of needs, 2) choice of siting criteria, 3) identification of alternative sites, and 4) evaluation of the sites. While the process is described below step-by-step, it should be practised in a cyclical manner, constantly reviewing and refining previous steps as the process proceeds. In particular, the process should iterate in a geographically hierarchical manner, beginning with general areas, with each succeeding iteration through the process screening down to more specific locations.

Only a general methodology for facility siting is described here, since details will necessarily differ from jurisdiction to jurisdiction. In fact, entirely different processes may be more appropriate for certain areas, although the issues and concerns discussed here should be addressed as part of any facility siting decision.

2.0 Siting methodology2.1 Assessment of needs

In this step, the types, sizes and number of facilities required should be determined. The choice of facility types is mainly dictated by the waste to be disposed of and the choice of treatment and disposal processes, as discussed elsewhere in this document. The first step in identifying the number and sizes of facilities for an area is to estimate the total required capacities for each type of process over a selected time horizon of, for example, 20 or 30 years. This requires knowledge of whom the system is to serve, e.g. what industries, etc., and forecasting their future needs for the disposal of hazardous materials. This procedure, although difficult and perhaps even tedious, should be attempted.

There are many ways, however, of meeting the required capacities, ranging from one centralized facility for the entire area to a highly decentralized system with many regional facilities. Different sites could have either the same treatment and disposal processes, i.e. parallel facilities, or different capabilities to serve different needs. The degree of centralization or decentralization of facilities can have significant economic, environmental and social/political effects. Table 1 below summarizes some of the significant advantages of centralized and of decentralized hazardous facilities. Centralized facilities enjoy economies of scale, allow for increased control and supervision of operations, and limit possible environmental risks to fewer areas. Decentralized facilities, on the other hand, require less transportation of hazardous materials, distribute the environmental risks among more of the population, and lessen the potential hazard to any single area. In addition, people usually are more willing to accept sites serving their own needs, rather than accept hazardous materials from other areas.

Forecasting future needs can, at best, be very approximate since it will depend on industrial development, future types of consumer goods, and what is identified as being toxic and hazardous in the future. These needs can be met either by building excess capacity now or by adding additional capacity as it is required. Future capacity expansion can be achieved, in turn, by adding new facilities or expanding existing ones. The amount of capacity that should be built at any given time will depend upon trade-offs between economies of scale from building larger facilities, on the one hand, and the increased cost of borrowing additional capital on the other. Uncertainties about future needs and the time required to expand facilities should also be considered.

Table 1. Advantages of centralized and of decentralized
 hazardous facilities

<u>Centralized</u>	<u>Decentralized</u>
Economies of scale for land, construction and operation;	Decreased transportation costs and Risk of transport accidents;
Increased control of operations possible;	Spreads environmental risks from sites among more of the population;
Limits possible environmental risks to fewer areas - "easier to monitor, control and rehabilitate.	People might be more willing to accept sites serving their own needs. Lessens the scale of potential hazards at each site.

2.2 Choice of siting criteria

Alternative sites should be evaluated and chosen on the basis of explicitly stated criteria (or objectives), which can be divided into four basic types: 1) economic, 2) environmental/health, 3) social/political, and 4) technical. Table 2 below illustrates the types of criteria that should be considered. While transport and land costs have traditionally been the major criteria for industrial facility location decisions, the location of facilities to treat and dispose of hazardous materials now requires a much broader perspective as a result of the potential impacts of such facilities.

From the large number of possible criteria to choose from, a relatively small manageable set of criteria should be chosen. This choice should depend upon the relevance and importance of the criteria, the comprehensiveness of the set, and nonredundancy between criteria.

Once the criteria have been selected, it is necessary to choose specific performance measures (including cost) which will reflect the degree to which each alternative site meets the criteria. There can be many possible performance measures for each criterion. For example, risks to public health from groundwater contamination by a landfill could be measured, at least in theory, by the likelihood of water supply contamination and illness or death, or by a "surrogate measure" such as the distance from the landfill to the groundwater or to the potentially affected population.

Table 2. Examples of siting criteria

Economic

- Transport costs to site
- Facility cost - land
 - additional design requirements
 - monitoring
 - closure
- Rehabilitation in case of "accident"

Environmental/health (public health risks from):

- Transport Accidents
- Surface Water Contamination
- Ground Water Contamination
- Air Pollution
- Food Chain Contamination

Social/political

- Current land use
- Density/closeness of local population

Technical

- Low potential for leachate contamination of ground and surface waters (affected by hydrogeology of site)
- High air pollution dispersion away from populated areas
- Adequate size and topography for facility and a buffer zone plus room for future expansion
- Existing transportation facilities (e.g. roads, rail lines) to site
- Compatible with an appropriate final use of site after closure

The choice of which measures to use can be crucial to the cost, usefulness and practicality of evaluating the sites. While the chosen set of measures should be able to reflect the desirability of each site, they should also be limited in number and be relatively easy to estimate accurately. Consideration should be given to the type of scale of measurement that can affect the meaningfulness and ease of estimation of a performance measure. Different types of scales convey different amounts of information and can be manipulated in different ways in an evaluation. While preference for the scale of measure will depend on the related criterion, quantitative are generally preferable to qualitative measures, and absolute to relative measures.

To measure the degree of achieving a criterion that is difficult to measure directly, a surrogate measure is often useful, where there is an indirect relationship between the surrogate measure and the criterion. As illustrated above, distance to groundwater could be a surrogate measure for the risk of groundwater contamination. In fact, technical criteria are generally surrogates for economic and environmental/health criteria.

Another issue is the use of constraints instead of objectives. A constraint is a minimum or maximum degree of effectiveness or cost that is to be met, and once it is met, no further consideration is given to it. With an objective, however, the desire is to achieve the best possible result. For example, there may be technical constraints, often called standards, on such things as soil type, distance to groundwater, or required buffer zone, budget constraints, a minimum level of acceptable risk to public health or distance to the nearest population centre, and legal constraints on type of land that may be withdrawn from its current use. Sites, however, can be judged on the basis of both criteria and constraints; only those sites that would meet certain constraints are to be considered, and site selection from among those remaining sites is to be made on the basis of the best attainment of the criteria. It is therefore also necessary to establish what, if any, constraints exist.

2.3 Identification of potential sites

The purpose of this stage of the process is to identify potentially acceptable sites, and to screen out those sites that do not meet the established constraints. As a first step, maps with appropriate resolution and information must be obtained. The information required would correspond to the criteria and constraints established in the previous step. This part of the process, in particular, might require several iterations to screen down to particular sites, with more detailed maps and constraints being used each time.

A useful technique for identifying potentially acceptable sites is "exclusionary mapping". In this method, the areas represented by the maps are considered with respect to the constraints one at a time; any site that does not meet any one of the constraints is eliminated from further consideration and only those sites that meet all of the constraints are considered further. A useful tool for exclusionary

mapping is map-overlays, where for each constraint a transparent material is placed on the map and shaded or darkened over the sites that do not meet the constraints. When all of the transparencies are laid together over the map, only those sites that meet all of the constraints will be seen.

If no sites meet all of the constraints, then consideration will have to be given to modifying or eliminating some of the constraints. Even if a site does not appear to meet certain constraints, it would often be possible to require additional facility design features at that site to bring it up to an acceptable level, though this would be at additional cost.

2.4 Evaluation of alternative sites

Facility siting decisions are generally characterized by multiple alternatives, conflicting objectives and interests, long-term consequences and uncertainty. Figure 1 is a convenient way to summarize these characteristics; each matrix element in the Figure contains information about the effect of an alternative on an interest group with respect to a criterion at a particular point in time. One of the important features in risk management is that there is uncertainty about the content of some of these matrix elements.

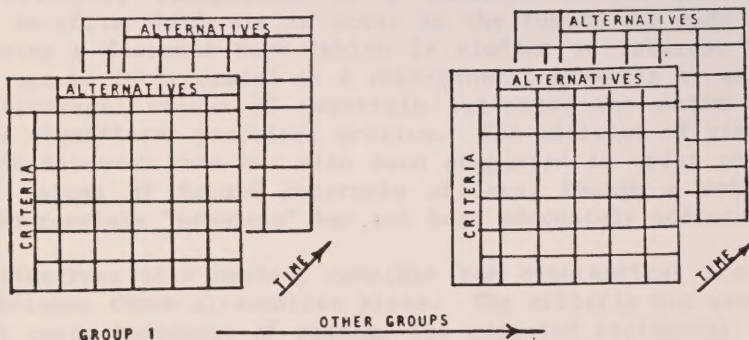


Fig. 1. Structure of information for risk management decision-making.

Estimation of the impacts for each site can be the most difficult, costly and time-consuming part of an evaluation. It should involve information and data from various sources including site investigations. The assessment of risks to public health from the transportation of wastes to the site and risks to the local population should be an integral part of the analysis.

Several techniques, each with numerous variants, have been developed to compare alternatives, by weighing the trade-offs between them, and to specify the alternative that should be chosen. One of

the most important of these techniques is "cost-benefit analysis". Each evaluation technique seeks to arrive at an overall value for each alternative, in order to allow comparison. These values are purported to represent the values to society of the alternatives. Each technique, therefore, implies either explicitly or implicitly, a social welfare function with assumptions about the relative importance of the various criteria, interest groups and effects over time in order to make the necessary trade-offs. The types of criteria that can be considered, the choice of measurement scale and valuation for the criteria, the treatment of risk, and the method of considering the distribution of effects can significantly affect the practicality of using an evaluation technique, and the validity and acceptability of its results.

Cost benefit analysis

Cost-benefit analysis (CBA) is, in theory, a method for comparing alternatives on the basis of economic efficiency, i.e. the degree to which each alternative contributes to society's wealth, as measured by certain economic criteria. Only those objectives which affect this economic wealth are considered. An overall value (termed "net present value") is calculated for each alternative in monetary units, requiring that all of the benefits and costs be valued in monetary terms. The valuations of these benefits and costs, which indicate the relative importance of the different effects, are made on the basis of economic criteria, independent of a decision-maker's preferences. Costs and benefits which are to occur in the future are made comparable by using a discount rate (which is similar to interest rates), and risks can be incorporated in a cost-benefit analysis by using the expected (average) values of uncertain outcomes, the estimation of which is a significant practical problem. The addition of risk premiums to the discount rate has also been suggested in order to "penalize" the values of future uncertain effects, though a method for choosing appropriate "premiums" has not been adequately addressed.

To illustrate this method, consider the hypothetical problem of choosing between three alternative sites. The criteria are assumed to be initial cost, incidence of cancer, and expected accidental deaths. Other costs and benefits are assumed to be the same across the three alternatives. (In an actual case, the list of criteria would be much longer.) As shown in Table 3, each alternative meets these criteria to a different degree, and none is best in all regards.

The problem is to combine the criteria in such a way as to identify the best alternative. Cost-benefit analysis does this by assigning a monetary value to each criterion. Therefore, if each accidental death and cancer case is assumed to be valued at \$300,000 and \$100,000, respectively, based as economic criteria such as loss of future earnings and the cost of medical care, using a 10% discount rate and a 50-year period of operation, the present value of these costs for alternative A is given by:

$$\begin{aligned}
 PVA &= \$5,000,000 + \sum_{t=1}^{50} \frac{3 \times \$100,000}{(1+0.10)^t} + \sum_{t=1}^{50} \frac{0.35 \times \$300,000}{(1+0.10)^t} \\
 &= \$5,000,000 + \$2,975,000 + \$1,041,000 = \$9,016,000
 \end{aligned}$$

Table 3. A hypothetical example of site selection

Alternative facility sites	Initial cost (\$ million)	Annual health effect (related incidents of cancer per year)	Accidental deaths (per accident)	Annual probability of an accident	Expected annual accidental deaths
A	5	3	70	0.005	0.35
B	6	4	40	0.001	0.04
C	4	2	100	0.01	1.0

Similarly, the present values for alternatives B and C are \$10,085,000 and \$8,958,000, respectively. Since C has the lowest present value of costs it should be preferred according to the cost-benefit analysis.

Several considerations are not included in conventional cost-benefit analysis, however. For example, cost-benefit analysis ignores "equity", i.e. the distribution of costs (including risks) and benefits, by considering only the aggregate of all of these values across the different groups; no distinction is made as to who benefits and who pays. Another problem is that consequences, such as pain and suffering, which either do not affect social wealth or upon which no monetary values can be placed, are ignored. One can imagine the restrictions this places on the valuations of consequences such as loss of life.

In summary, conventional cost-benefit analysis for the evaluation of alternative risk management can be a valuable tool for measuring each alternative's economic effect. This is an important factor, though not the only one, that should be considered in an evaluation.

Modifications can be made to conventional cost-benefit analysis to incorporate non-economic factors. Many of these changes move the technique from the realm of objective to subjective rationality. Subjective preferences can be applied to the weighting of objectives of different interest groups. With the use of weights, any objective can be considered. For example, Hettich (1971) has suggested a method for including distributional concerns within the cost-benefit analysis framework by undertaking the analysis for each interest group separately and then combining these results according to stated preferences for the different groups. The difficulties in estimating weights can, however, be a major source of concern.

Cost-effectiveness and risk benefit analysis

Cost-benefit analysis requires that all effects be valued on a monetary scale in order to arrive at a single overall value for each alternative. Cost-effectiveness analysis, on the other hand, acknowledges the difficulty (or impossibility) of explicitly valuing benefits (effectiveness) in the same units as costs. In facility siting problems, "effectiveness" might be a measure of risk, such as the probability of no accident, and "cost" might be an economic measure of the system net costs or benefits, perhaps based on a cost-benefit analysis. Hence this is sometimes referred to as risk-benefit analysis.

For the siting example (Table 3), effectiveness could be expected annual accidental deaths, and net costs could be the present value of the initial and health effects costs. The combination of costs and effectiveness for the three alternatives are shown in Figure 2, where each point corresponds to a different alternative. The points have been joined to form a cost-effectiveness curve, assuming that a large number of alternatives is available. The shape illustrated, showing first an increasing slope and then a decreasing slope, is typical since we can often achieve considerable improvements with initial sums of money, but eventually it becomes increasingly expensive to do much better. The hatched area of Figure 2 represents families of solutions, all of which are less cost-effective than those on the curve. In the unhatched area, no solutions are possible.

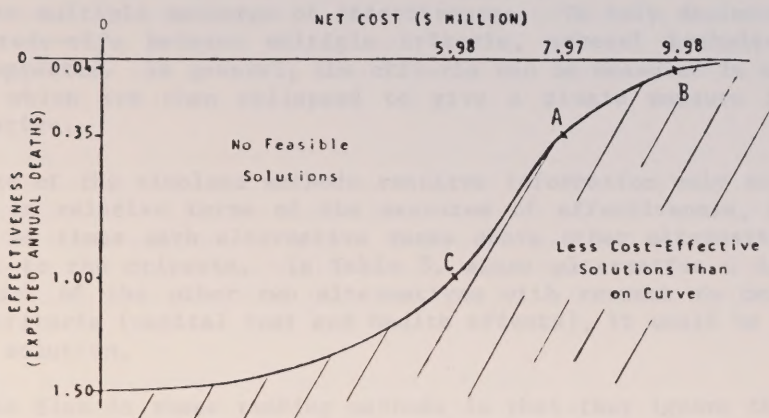


Figure 2. Cost-effectiveness curve

The decision-maker must decide which combination of effectiveness and net cost is best. For example, he might choose point A believing that, compared with point C, the increased effectiveness is worth the additional cost, but that it is not worthwhile to achieve the additional effectiveness of point B. Alternatively, he might choose the alternative that simply achieves a chosen minimum acceptable level of effectiveness (such as minimum acceptable risk). Notice that this does not require an explicit valuation of effectiveness relative to the costs. When effectiveness is a measure of risk, the decision-maker must make assumptions about society's attitudes toward both taking risks and accepting different degrees of effectiveness, e.g. the valuation of the probabilities of system failure, when making a decision. Though not needing to define these preferences explicitly simplifies the analysis, it makes the evaluation and selection less open to scrutiny and possibly more arbitrary.

Closely related to cost-effectiveness analysis is the concept of marginal (additional) cost for a unit increase in effectiveness; for example, the cost per life saved. This quantity, as measured by the

slope of the cost-effectiveness curve, can be very useful when addressing the basic problem of rationally allocating limited funds among a number of different programs, each of which can contribute to increased effectiveness at different costs. For example, government can save lives through programs in highway safety, medical diagnosis and hazardous waste management. Because its budget is limited, however, the government must address the question of how much should be spent on each program.

Multi-criteria analysis

Cost-effectiveness analysis is easy to undertake when effectiveness is in terms of a single measure. However, it is often not reasonable to define effectiveness so simply, and the analysis must be based on multiple measures of effectiveness. To help decision-makers make trade-offs between multiple criteria, several techniques have been suggested. In general, the criteria can be measured in different terms, which are then collapsed to give a single measure for each alternative.

One of the simplest methods requires information only on the ordering in relative terms of the measures of effectiveness, e.g. the number of times each alternative ranks above other alternatives with respect to the criteria. In Table 3, since alternative C is better than each of the other two alternatives with respect to two of the three criteria (capital cost and health effects), it would be the preferred solution.

The flaw in these ranking methods is that they ignore the degree to which the alternatives differ in meeting the criteria; they also ignore differences in the importance of the different criteria. In effect, these techniques assume that all criteria are equally important. The results, therefore, can be highly dependent upon the particular way in which the criteria are stated.

Another major class of multi-criteria techniques involves the rating of the alternatives with respect to each criterion, the weighting of the criteria to reflect relative importance, and then the combination of these ratings and weights to give an overall rating of each alternative, using, for example, a linear weighting function.

For the example given in Table 3, assuming for purposes of illustration that weights of 1, 1.5 and 4 are assigned for initial costs (in \$ 10⁶), annual cancer cases and expected annual accidental deaths, respectively, the overall rating (using a linear weighting function) for alternative A is:

$$R_A = 1(5) + 1.5(3) + 4(0.35) = 10.90$$

Similarly,

$$R_B = 1(6) + 1.5(4) + 4(0.04) = 12.16$$

$$R_C = 1(4) + 1.5(2) + 4(1.0) = 11.0$$

Since Alternative A has the lowest rating, it would have the lowest overall "cost" and thus would be considered to be best.

Cost-benefit analysis is a form of rating technique with the valuations of benefits and costs corresponding to the weights. The reverse is also true - when a rating technique is used with both monetary and non-monetary objectives, the relative weights imply a monetary valuation for the non-monetary effects. For annual deaths and initial costs having weights of 4 and 1, respectively, a death can be imputed to have a value (cost) of $4/9.915 = 0.403$ million dollars, where 9.915 is the "present value factor" using a 10% discount rate and 50 years life.

In another variation of the rating technique, all of the ratings are put on a common scale, such as 0 to 10, called "scores", which are then weighted to yield an overall score for each alternative. Extensions of these methods have been suggested to consider different interest groups by evaluating the alternatives for each group separately (using weights appropriate for the group) and then weighting the groups.

The determination of appropriate weights is crucial to the usefulness of the results of a multi-criteria evaluation. Though the various techniques can be useful, no method can be relied upon alone for site evaluation. Rather, each should be considered as a tool available to the decision-maker.

Decision analysis

The problem facing a decision-maker is twofold. First, he needs to choose the decision criterion that is most appropriate for society. Then, he must identify the alternative decision that should be most preferred according to the chosen decision criterion. Each decision criterion implies a different psychological premise concerning attitudes toward either taking risks or the probabilities of each of the possible future chance events. For example, society might be highly risk averse with respect to particular outcomes such as the loss of life.

In decision analysis which uses an expected utility criterion, it is generally helpful to prepare a decision tree, as illustrated in Figure 3 for the hypothetical example. Each branch of the tree represents either a decision or a chance event that may occur subsequent to a decision. The analyst must estimate the probability of the occurrence of each event. These probabilities may, for instance, be based on empirical evidence or on an expert's subjective judgements. Each chance event in turn may be followed by other decisions and pos-

sible events. For example, the tree may be structured with multiple stages to allow for an analysis of experience gained, with data helping to improve estimates of the probabilities of the chance event branches in the following stages.

Each path on the tree leads to the outcomes that would occur if the corresponding sequence of decisions and events were to happen. Figure 3 shows that initial cost and annual number of cancer cases are the same for each chance event for a given alternative. However, the number of possible accidental deaths over the 50 year life ranges from 0-3500 for Alternative A, from 0-2000 for Alternative B, and from 0-5000 for Alternative C.

Each set of alternatives is then assigned a utility value which incorporates the decision-maker's attitude toward taking risks. A major issue in the use of decision analysis for public decisions is whose preferences to use, since utility functions are defined for individuals. The alternative that has the highest expected utility is best using decision analysis. If the decision-maker is highly risk averse with respect to accidental deaths, he would tend to prefer Alternative B with its much lower risk of fatalities. The analysis, however, would consider the trade-offs among the three criteria.

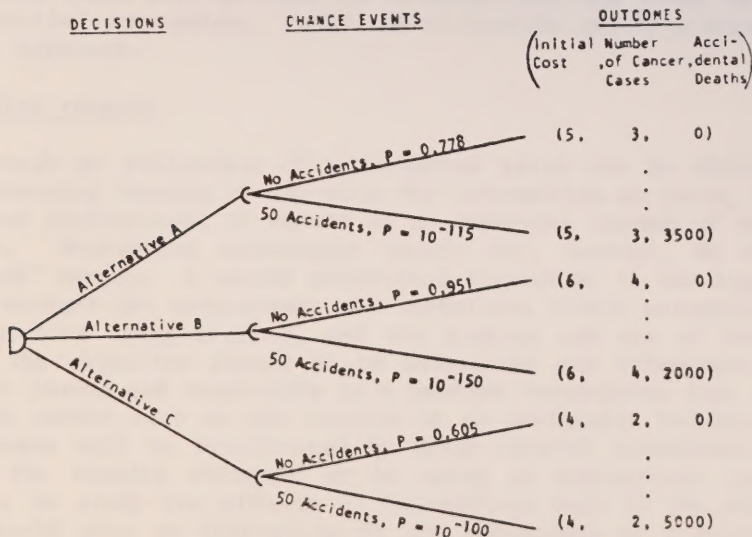


Figure 3. Decision tree for hypothetical example. The top and bottom chance event branches for Alternative A are, respectively: no accidents over the life of the facility; and one accident each year (or 50 accidents). The probability of no accidents is $(1.0 - 0.005)^{50} = 0.778$ and of one each year is $(0.005)^{50} = 10^{-115}$. Other possible chance events would be represented by other branches and appropriate probabilities of occurrence would be estimated.

Other approaches

In the techniques discussed above, explicit or implicit assumptions are made about preferences. An alternative procedure that does not require a priori assumptions about distribution issues, or comparisons of the preferences of the different interested parties, is a collective decision-making process with implicit or explicit negotiations or mediation between the parties. In this type of process, these parties, rather than the risk manager, identify the alternative to be recommended. The negotiations in this process may, for example, focus directly on which alternative to choose, or indirectly on the choice of decision criterion. Compensation of one party by another may, for instance, be part of the compromise. Collective decision-making is a practical method for making social decisions which may result in a suitable compromise between opposing parties. By bringing the interested parties into the decision-making process, the parties may feel that they have a stake in seeing that their proposal is implemented. Unfortunately, a compromise may not always be reached.

Within this framework, it is the task of the risk manager to help the interested parties reach a compromise, rather than dictate a solution for them. He can provide the parties with organizational advice, and can illuminate the preferences and preferred alternative of each party, the trade-offs between the alternatives, and areas of conflict and potential compromise. Public participation can be a valuable part of this approach.

Concluding remarks

Though an evaluation of alternative sites can be difficult and time consuming because of the need for information on costs, benefits, risks and preferences, it should be an essential element of waste management. Evaluation techniques should not, however, be used in a "cookbook" manner. A needed additional ingredient is the ingenuity of a risk manager who understands the techniques (their assumptions etc.) - the problem being studied, and the purpose and use of the evaluation. The objective should be to understand and illuminate the significant issues and trade-offs in a problem recognizing that the final decision cannot rest on the results of an evaluation technique alone. The process will be facilitated by using several techniques and comparing the results obtained or by using an appropriate sensitivity analysis to study the effects of assumptions made in the evaluation. This should give an indication of the robustness of a solution. In this connection, adaptive strategies might be employed so that if an alternative scenario begins to develop, the waste management plan can be adjusted accordingly. In order to do this, an organized effort must be made to monitor the situation at regular intervals.

The problem

The problem of burning the waste of a manufacturing company, such as the Lawrence Cement Co. in Mississauga, Ontario, has been a long and difficult one. The waste is a highly toxic material, and its burning is a complex process. The problem is to find a way to burn the waste safely and efficiently, without causing any harm to the environment or to the people living nearby.

APPENDIX D

THE BURNING OF PCB'S
AT ST. LAWRENCE CEMENT, MISSISSAUGA
ONTARIO, CANADA:
A CASE STUDY

The problem

One of the most serious environmental problems in the world today is the burning of waste. The burning of waste is a complex process, and it is one that is often misunderstood. The burning of waste is a process that is often used to dispose of waste, but it is a process that is often done in a way that is harmful to the environment. The burning of waste is a process that is often done in a way that is harmful to the environment, and it is a process that is often done in a way that is harmful to the people living nearby.

PETER TIMMERMAN

Starting in 1977, approximately 10 tonnes of waste were burned at the St. Lawrence Cement Co. in Mississauga, Ontario. The waste was a highly toxic material, and its burning was a complex process. The burning of waste is a process that is often used to dispose of waste, but it is a process that is often done in a way that is harmful to the environment. The burning of waste is a process that is often done in a way that is harmful to the environment, and it is a process that is often done in a way that is harmful to the people living nearby.

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Introduction

The attempt to undertake the burning of polychlorinated biphenyls (PCB's) at St. Lawrence Cement in Mississauga, Ontario, was an example of a common situation in present day management of hazardous waste: a good technical solution to a problem faltered because of inadequate attention to public concerns. Since the proposers of the project have admitted errors in judgement, and since a completely new approach to the problem is in progress, a short self-contained description of the project's history is possible. It is hoped that it may serve as a limited case study for managers elsewhere.

The project

Because of the effectiveness of high-temperature incineration in the destruction of hazardous waste, a great deal of attention has been paid to the possibility of using cement kilns already operated by industries. Cement kilns are an attractive technology, because their temperatures and gaseous residence times are as good or better than hazardous waste incinerators. The turbulence of the system provides for good mixing, and the highly alkaline environment traps acid gases and heavy metals (Oppelt, 1982). In addition, waste oils can be used as a fuel supplement in the cement-making process, thus providing energy savings.

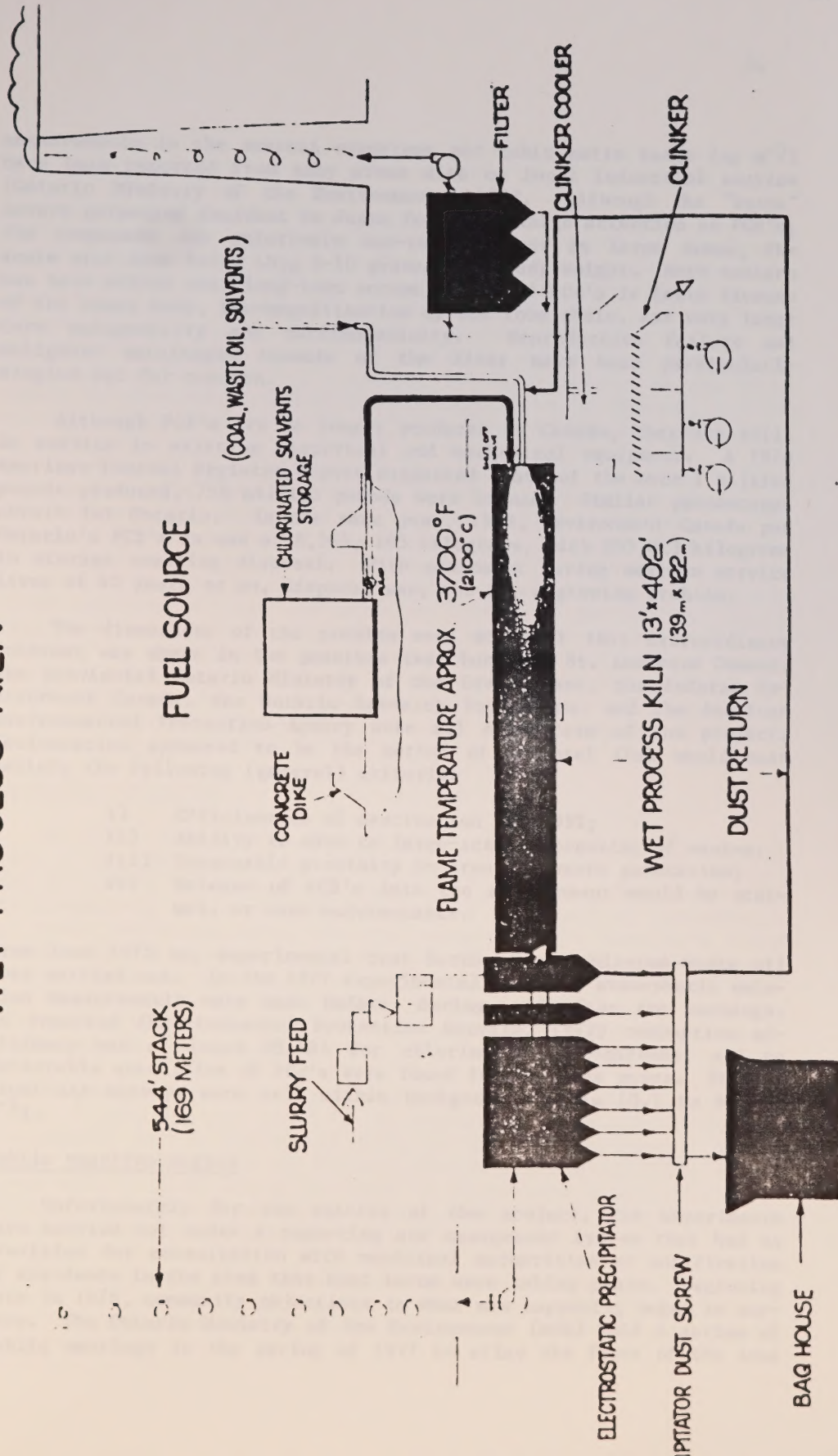
Starting in 1973, experiments in burning lubricating oils were carried out at St. Lawrence Cement in Mississauga, Ontario. St. Lawrence Cement has two wet process long kilns, 400 feet long (122 metres) and 11 feet in diameter (3.3 metres) at their narrowest points. The waste oils and solvents were added to the fuel burners that fuse cement slurry at intense heat (2100°C) (see Figure 1). Handled properly, the process can destroy over 99% of the waste materials introduced. Indeed, so successful were these initial experiments, that the company and the federal Environment Canada office suggested that further experiments be conducted into the possibility of burning fuel supplements containing substantial quantities of chlorinated hydrocarbons, including PCB's. It was felt that this might help solve the growing problem of what to do with PCB's.

PCB's - a mixture of chemical compounds based on the attachment of various chlorine atoms to a two benzene molecule called a biphenyl - were originally put into commercial production (in 1929) because of their thermal stability, resistance to other chemical agents, and their outstanding electrical insulating properties (File et al., 1980). Until their restriction in the 1970's, approximately 1.4 billion pounds were produced in North America alone. PCB's were widely used as electrical insulating fluids in transformers, as plasticisers, hydraulic fluids, and in cooling systems. Unfortunately, their very stability also ensures that PCB's are extraordinarily persistent in the environment.

There is widespread residue contamination of PCB's in air, water, sediments, and soils throughout North America, and the world. Air

FIGURE 1:

PROCESS-SOLVENT BURNING WET PROCESS KILN



(Source: Ontario Ministry of the Environment
n.d.)

measurements in the several nanograms per cubic metre range (ng m^{-3}) have been reported from many areas with no local industrial sources (Ontario Ministry of the Environment, 1978). Although the "Yusho" severe poisoning incident in Japan focussed public attention on PCB's, the compounds are relatively non-toxic except in large doses, the acute oral dose being LD_{50} 1-10 grams/kg of body weight. More concern has been voiced over long-term accumulations of PCB's in fatty tissues of the human body, bio-magnification up the food chain, and very long-term mutagenicity and carcinogenicity. Reproductive failure and malignant carcinogen tumours of the liver have been particularly singled out for concern.

Although PCB's are no longer produced in Canada, they are still in service in existing electrical and mechanical equipment. A 1978 American Federal Register report suggested that, of the over 1 billion pounds produced, 758 million pounds were in use. Similar percentages obtain for Ontario. In the same year, 1978, Environment Canada put Ontario's PCB's in use at 8,565, 185 kilograms, with 203,023 kilograms in storage awaiting disposal. With equipment having maximum service lives of 40 years or so, disposal was, and is, a growing problem.

The dimensions of the problem were so great that extraordinary interest was shown in the possible test burns at St. Lawrence Cement. The provincial Ontario Ministry of the Environment, the federal Environment Canada, the Ontario Research Foundation, and the American Environmental Protection Agency were all supporters of the project. Incineration appeared to be the method of disposal that would best satisfy the following (general) criteria:

- i) Efficiencies of destruction over 99%;
- ii) Ability to move to large-scale processing of wastes;
- iii) Reasonable proximity to areas of waste generation;
- iv) Release of PCB's into the environment would be minimal, or even undetectable.

From June 1975 on, experimental test burns of contaminated waste oil were carried out. In the 1977 experimental program, atmospheric emission measurements were made before, during, and after the burnings. As reported (Environmental Protection Service, 1977) combustion efficiency was at least 99.986 for chlorinated hydrocarbons, and no detectable quantities of PCB's were found in the stack gases. The ambient air surveys were well within background levels (0.1 to 4.5 ng m^{-3}).

Public reaction begins

Unfortunately for the success of the project, the experiments were carried out under a reporting and management system that had no provision for consultation with municipal authorities or notification of residents in the area that test burns were taking place. Beginning late in 1976, community objections to what was happening began to surface. The Ontario Ministry of the Environment (MOE) held a series of public meetings in the spring of 1977 to allay the fears of the area

residents, but these meetings appear to have been largely public relations exercises which merely served to aggravate local hostility.

This hostility was further aggravated when it was revealed in the press both that the experimental burnings of waste oil had now become standard operating procedure at St. Lawrence Cement, and that there was substantial confusion over the status of the Certificates of Approval being given to the various projects. This meant that the simple burning of lubricating oils became inextricably bound up with the experimental burnings of oils substantially contaminated with PCB's. Under substantial political pressure, the then Minister of the Environment withdrew St. Lawrence Cement's Certificate of Approval for PCB burnings subject to a review by an Environmental Assessment Board.

At the same time, however, St. Lawrence Cement continued to burn waste lubricating oils, etcetera, in its cement-making processes. Although very low amounts of PCB's were to be found in these oils, they became the subject of sporadic reports and accusation in the media and elsewhere during the ensuing months. By this time, the citizens, municipal politicians, and special-interest groups had become better organized and were now uniformly hostile to any continuation of the project in any form. They began to widen out the scope of their concerns, so that issues such as the increased likelihood of transportation accidents around the plant, possible accidents in the cement-making process, inadequate testing procedures by the Ministry, and the assessment of possible alternative technologies became part of the opposition "armoury".

The Royal Commission

In 1978, the, A Royal Commission of Inquiry Into the Burning of PCB's at St. Lawrence Cement in Mississauga was set up by the provincial government under The Public Inquiries Act, 1971. This commission was immediately challenged by court action on behalf of Mississauga, the basic contention being that the mandate of the commission under the act was too narrowly defined, i.e. the opponents wished to have the commission consider the entire issue of burning PCB's in an urban area at all, while they interpreted the commission's mandate as being simply to consider the merits of the particular experiment. Public opinion was further polarized.

As perhaps the final straw, the Director of the Waste Management Branch of MOE, who was asked by the commission to prepare a "Director's Report" on the burning of PCB's at St. Lawrence Cement, recommended that Certificates of Approval for utilization of PCB's in the cement-kiln process should be based on documented experimental evidence of the minimum conditions necessary for PCB destruction, using new field monitoring equipment:

The tests will be carried over a sufficient period of time to produce a stronger data base from which to draw clear, unquestionable conclusions about the technical performance

of the St. Lawrence Cement manufacturing process in the destruction of PCB. (Ontario Ministry of the Environment, 1978).

From the point of view of the Ministry, this was an eminently sensible way of obtaining exactly the information required to determine the efficacy of the process and the danger to the residents in the area around the plant. And, in September 1979, provisional approval for the test burns was given by the Ministry of the Environment. The City of Mississauga immediately passed a bylaw prohibiting the burning of PCB's for any reason in the city. Two weeks later, they passed a slightly more conciliatory by-law allowing the test burnings only if assurances were made that St. Lawrence Cement would not become a future disposal facility. A new legal battle began between the province and the municipality. A PCB Test Burn Liaison Committee was set up as a network of citizens and others to garner financial support and enlist expert aid.

A report on the situation at this time noted:

In the context of the urgent need to find a safe disposal method for toxic wastes, and in the absence of insurmountable technological barriers to PCB destruction, political concerns appear as the greatest obstacles. Awaiting the resolution of political differences, communication is inhibited, and the real issues are all but ignored. (File et al., 1980).

The next step

It was substantially clear by this time that, although the province might succeed in its legal battles, the political situation had reached something of a stalemate in the face of the implacable opposition of the residents. Furthermore, it was unlikely that the Royal Commission would make any decision on the matter until probably 1982. MOE thus hired a consulting firm to design and oversee an interim storage facility for PCB's in light of the obvious fact that no permanent solution was to be expected for a number of years, and also because there was a threat that the American border would be closed to cross-border disposal traffic, eliminating that alternative. This storage facility would be subject to full environmental assessment hearing.

By this time, however, a bewildering array of choices and alternatives for destruction of PCB's, including plasma arc torches, wet air oxidation, and portable diesel destruction units, had either come on the market or were in the experimental stages. Faced with assessing these methods, handling the siting problem, and generally managing the liquid industrial waste streams in the province, it was ultimately decided to create a Waste Management Corporation (announced in November 1981) with responsibility for the safe treatment and disposal of all hazardous wastes generated in the province of Ontario. A comprehensive plan is to be produced by the Corporation, with the setting up of a full-scale waste-treatment facility as one possible goal.

By its very nature and mandate, the creation of the Waste Management Corporation has brought to a temporary conclusion the search for a method and a site for the burning of PCB's in Ontario.

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ANNOUNCEMENT

Respectfully, the undersigned, J. Edgar Hoover, Director, Federal Bureau of Investigation, U. S. Department of Justice, hereby announces that the following persons have been appointed to the following positions:

Mr. J. Edgar Hoover, Director, Federal Bureau of Investigation, U. S. Department of Justice, has appointed Mr. J. Edgar Hoover, Jr., to the position of Assistant Director, Federal Bureau of Investigation, U. S. Department of Justice.

Mr. J. Edgar Hoover, Jr., is a native-born American citizen, born on January 1, 1901, at St. Louis, Missouri. He is a graduate of the University of Missouri, St. Louis, and of the University of Chicago, Chicago, Illinois.

Mr. J. Edgar Hoover, Jr., has been employed by the Federal Bureau of Investigation, U. S. Department of Justice, since 1921, and has held the position of Assistant Director since 1931.

Mr. J. Edgar Hoover, Jr., is a member of the American Bar Association, the American Association of University Professors, the American Association of Social Workers, and the American Association of Public Administrators.

Mr. J. Edgar Hoover, Jr., is a member of the Executive Committee of the American Association of University Professors, and is a member of the Board of Directors of the American Association of Social Workers.

Mr. J. Edgar Hoover, Jr., is a member of the Board of Directors of the American Association of Public Administrators, and is a member of the Board of Directors of the American Association of University Professors.

Mr. J. Edgar Hoover, Jr., is a member of the Board of Directors of the American Association of Social Workers, and is a member of the Board of Directors of the American Association of Public Administrators.

Mr. J. Edgar Hoover, Jr., is a member of the Board of Directors of the American Association of University Professors, and is a member of the Board of Directors of the American Association of Social Workers.